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PROJECT ADMINISTRATION DATA SHEET

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[ ] REVISION NO. _____

Project No. A-2968 | DATE: 6/19/81

Project Director: Dr. David S. Ladd | ~~SXXXXX~~/Lab RAIL/RED

Sponsor: USAERAD Com; Ft. Monmouth, N. J.

Type Agreement: Short Form Research Contract (SFRC) DAAK20-81-K-1001

Award Period: From 6/1/81 To 2/1/82 (Performance) - - - - - (Reports)

Sponsor Amount: $99,416 | Contracted through:

Cost Sharing: N/A | GTRI/GIT

Title: Development of a Compact Nanosecond Modulator for the 95 GHz EIA

ADMINISTRATIVE DATA | OCA CONTACT William F. Brown x4820

1) Sponsor Technical Contact: Mr. J. Carter (DELET-BG) Beam, Plasma and Display Division; ETD Laboratory (ERADCOM), Fort Monmouth, NJ 07703

2) Sponsor Admin./Contractual Contact: Mr. Thomas A. Bryant, ONR-RR, 206 O'Keefe Building, Georgia Institute of Technology, Atlanta, Georgia 30332

Reports: See Deliverable Schedule | Security Classification: Unclassified

Defense Priority Rating: ____

RESTRICTIONS

See Attached Gov't. Contract Supplemental Information Sheet for Additional Requirements

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SPONSORED PROJECT TERMINATION/CLOSEOUT SHEET

Date 2/10/84

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Project Director(s) J. C. Butterworth   GTRI / ~~EES~~

Sponsor US Army ERADCOM, Ft. Monmouth, NJ

Title Development of a Compact Nanosecond Modulator for the 95 GHz EIA

Effective Completion Date: 2/28/83 (Performance) 2/28/83 (Reports)

Grant/Contract Closeout Actions Remaining:

- [ ] None
- [x] Final Invoice or Final Fiscal Report
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Georgia Institute of Technology

ENGINEERING EXPERIMENT STATION

ATLANTA, GEORGIA 30332

10 November 1981

Mr. J. Carter
DGLET-BG Beam, Plasma & Display
Division
ET&D Laboratory (ERADCOM)
Ft. Monmouth, New Jersey 07703

Subject: Contract Funds Status Report Covering the Period 1 June 1981 to 31 August 1981 for Contract DAAK20-81-K-1001

Gentlemen:

The financial status of the subject contract for the period from 1 June 1981 to 31 August 1981 is indicated below. Work is proceeding on schedule and expenditures are currently within budget. Delivery of the Compact Nanosecond Modulator should be on time and will require no additional funds.

Financial Status

Personal Services, Retirement and Overhead

Budget Amount	$65,716
Expended	26,496
Balance	$39,220

Travel, Materials and Supplies

Budget Amount	$33,700
Expended	518
Encumbered	561
Balance	$32,621

Total

Budget Amount	$99,416
Expended	27,014
Encumbered	561
Balance	$71,841

Respectfully submitted,

[redacted]

David S. Ladd
Project Director

Approved:

[redacted]

N. C. Currie, Chief
Radar Experimental Division

DEVELOPMENT OF A COMPACT NANOSECOND PULSER
FOR THE 95 GHz EIA

D. S. Ladd, G. M. Conrad, P. Fenoglio

Final Report on
Contract DAAK20-81-K-1001

Prepared for:

U.S. Army ERADCOM
Beam, Plasma & Display Division
DELET-BG

Prepared by:

Georgia Institute of Technology
Engineering Experiment Station
Atlanta, Georgia 30332

August 1982

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SECTION 1
INTRODUCTION

1.1 SCOPE

This report covers the development of a compact nanosecond pulser for the Varian Model VKB 2449T1 95 GHz extended interaction amplifier (EIA). The specific objectives and requirements of the pulser are presented and the EIA short pulse characteristics which impact the pulser design are discussed. The desired performance is defined, and the successful pulser design is detailed. A discussion of the auxiliary circuits, packaging and operating procedure follows. Data on the achieved performance are then presented. This report concludes with recommendations for further development which will lead to improved performance, reliability, and reduced size and weight.

1.2 OBJECTIVES

The primary objective of this program was the development of a pulser for the 95 GHz EIA which would be capable of producing pulses with extremely narrow pulse width and high pulse repetition frequency. A further concern was to determine and execute the optimum design approach in terms of size, weight, life, reliability, circuit simplicity and maintainability. The results of this program may well lead to the development of pulsers for use in airborne high resolution radar systems.

A second objective was to characterize the behavior of the EIA, particularly for short pulse widths. Although no model VKB 2449T1 EIA could be furnished for characterization, an effort was made to predict the behavior of the EIA from the data and experience gained in operating various other Varian extended interaction devices. The predictions can be tested when a VKB 2449T1 can be made available.

A third objective was to determine other design approaches which might yield better overall performance in specific applications and to suggest areas of improvement in the design that was developed.

1.3 REQUIREMENTS

1.3.1 GENERAL

The nanosecond pulser developed under this program is capable of charging and discharging the capacitance of the EIA grid with sufficient speed to assure nanosecond pulsing by using an on/off switching technique. This technique employs planar triodes, power MOS FETs and avalanche transistors in a push-pull circuit. Consideration was given to preserving the fast rise time properties of the pulse circuit by minimizing stray capacitance and inductance.

The pulser unit includes (1) power supplies, (2) modulator, and (3) trigger and control circuitry. The tube is protected by current-limited, high voltage power supplies and low energy storage in the high voltage coupling and bypass circuitry.

1.3.2 SPECIFIC GOALS

Table I lists the specific requirements for the nanosecond pulser and the actual performance achieved or demonstrated in the unit developed.

TABLE 1. NANOSECOND MODULATOR SPECIFICATIONS
FOR EIA TUBE MODEL VKB 2449T1

Specific Requirements	Goal	Performance Achieved
Peak power	1 kW	1 kW
Peak pulse voltage	3 kV	3 kV
Peak cathode current	1 A	1 A
PRF	20 kHz	20 kHz
RF pulse width (50%)	4 ns to 500 ns	1.4 ns to 100 ns
RF rise & falltime (10% to 90%)	2 ns max	.8 ns
Volume (modulator)	3 liters max	N/A
Weight (modulator)	2.5 kgm max	N/A
Volume (modulator plus power supplies & trigger)	4.0 liters max	11 liters
Weight (modulator plus power supplies & trigger)	3.5 kgm max	5 kgm
MTBF	1000 hrs min	Undetermined
Jitter	0.5 ns max	0.1 ns
Input voltage	28 Vdc	28 Vdc
Phase variation	4°	Undetermined

These requirements were based on the operating characteristics of the cathode pulsed EIA VKB 2400T. They were later amended for the VKB 2449T1 focus electrode controlled (FEC) EIA before this tube had been fully characterized for both short and long pulse behavior. The original design approach could not give both long pulses and short pulses. Therefore, the pulser design was optimized for best short pulse performance. This design resulted in a much shorter pulse width than thought possible. Although the long pulse width goal was not achieved with the unit developed, Section 6.1 gives a pulser design approach which should yield both good long pulse and short pulse performance.

SECTION 2

EIA OPERATING CHARACTERISTICS

2.1 BACKGROUND

The investigation of the operating characteristics of the extended interaction amplifier began with earlier investigations of the extended interaction oscillator (EIO). The EIO was first developed as a CW oscillator in the early 1970s. In 1978, the EIO was modified to produce high peak power pulses at millimeter wavelengths. Since that time, the EIO has become the most widely used high power tube in instrumentation and developmental millimeter wave radar transmitters, including 13 units developed at Georgia Tech. This cathode pulsed EIO is operated by applying a -13 kV pulse to the cathode which is biased at the dc anode potential of -8 kV for a total beam voltage of -21 kV. [1] Observations have shown that the RF produced by the cathode pulsed EIO is delayed from the voltage pulse and "snaps on" with a rise time on the order of one nanosecond. [2]

In 1981, Varian developed the nonintercepting focus electrode or "gridded" electron gun which allows the EIO or EIA to be operated in the manner of a conventional grid modulated TWT. The cathode is operated at -21 kV dc and the beam is cut off with -2.8 kV on the grid with respect to the cathode. The focus electrode controlled gun has been used in both the EIO and the EIA. As expected, the delay and "snap on" RF behavior also occurs in the gridded EIO, since the delay and "snap on" is the result of the exponential building of the RF oscillation from the noise level in the oscillator. In a test conducted at Varian, Canada, on the first gridded EIO, a nanosecond pulse capability was demonstrated using the technique of injection priming. [3] In further tests it was demonstrated that the EIO output was coherent with the injected RF signal.

---

[1] Ewell, G.W., Ladd, D.S., and Butterworth, J.C., "Operation of Pulsed Millimeter Wavelength Extended Interaction Oscillators," 1 Proceedings IEEE/MTT-S Symposium, May 1979.

[2] Ladd, D.S. and Butterworth, J.C., "Design Criteria for Compact Nanosecond Modulators for EIO's and EIA's," Final Technical Report, Contract DAAG29-76-D-0100, October 1980.

[3] Ladd, D.S., Conrad, G.M. and Butterworth, J.C., "Design Criteria for Compact Nanosecond Modulators for Gridded EIO's and EIA's," Final Technical Report, Contract DAAG29-76-D-0100, June 1981.

This indicated that the EIO could be injection locked.[4] In addition, one of the first cathode pulsed EIAs was tested and observed to have discernible delay in the RF pulse with respect to the beam current pulse.

2.2 APPLICABLE EIO CHARACTERISTICS

The function of the pulser/power supply is to apply the required dc and pulsed voltage waveforms to the electrodes of the RF transmitting tube which will result in the desired RF pulse performance. Accomplishment of desired RF pulse performance requires determination of the exact relationship between the RF pulse power, the RF phase or frequency, and the electrode pulse voltages.

At the time the pulser was developed, the RF voltage characterization for the VKB 2449T1 had not been done. This tube was available for only a few hours during which only the short pulse test could be performed. Therefore, the characteristics of the VKB 2449T1 are inferred from the data taken on the gridded EIO VKB 2445T. During the short pulse test, the gridded EIA was observed to behave in a manner consistent with the predictions based on the data from the gridded EIO, except that no discernible delay was apparent between the RF and the collector current pulse.

Figure 2.1 shows the EIA pulse and dc voltages and currents in a pulsed, suppressed collector circuit. The grid of the EIA is biased at -2.8 kV with respect to the cathode during the interpulse period. During the pulse rise time, most of the beam current is intercepted by the body. As the grid voltage approaches -21 kV, i.e., the dc cathode potential, the electron beam is focused through the slow wave structure or body to be intercepted by the collector. Beam transmissions of 97% have been achieved in the 95 GHz EIO.

Capacitors C_{KB} and C_{KC} provide the pulse current bypass for the cathode and collector. Resistor R_{CB} isolates the collector pulse current I_C from the body causing I_C to flow back to the cathode through C_{KC}. The result is that the voltage droop due to I_C appears from the collector to body since only the body current, I_B flows through C_{KB}. Given that R_C is large such that:

$$\frac{t}{R_C C_{KC}} >> \frac{I_B}{I_C}$$

[4] Ladd, D.S., "Nanosecond Behavior of Extended Interaction Oscillators," Proceedings Tri-Service Radar Symposium, October 1981.

where t is the pulse width, the collector voltage droop is given by:

$$V_K = \frac{I_B t}{C_{KC}}$$

Care must be taken to prevent the peak collector voltage from exceeding the rated value. The use of this circuit allows low energy storage in the power supply with low droop on the cathode voltage which has a high voltage phase or voltage-frequency pushing figure.

A plot of the body intercept current (I_B) as a function of the grid-cathode voltage (V_{GK}) is found in Figure 2.2. The focusing of the beam through the interaction region is shown by the null at V_{GK} = 0 volts.

The relationship between the RF power, the collector current I_C, and V_{GK} is shown in Figure 2.3. Note that the RF rise time from 10 dB to 0.5 dB (10% to 90%) occurs between V_{GK} = -150 V and V_{GK} = -50 V which is only 100 V out of the 2.8 kV swing of V_{GK}. It is this high RF-voltage sensitivity that has resulted in the successful nanosecond operation of both the EIA and the EIO as will be shown.

Figure 2.4 shows the RF power and frequency as a function of V_{GK} in the -60 V to +60 V range. Note that both the RF power and frequency are strongly affected by small changes in V_{GK}. For applications requiring high frequency and power stability, the peak grid voltage must have very low droop and ripple across the top of the pulse. In most cases this is on the order of one percent or less of the pulse voltage. A combined ripple and droop of less than 10 V has been demonstrated by measurement of the intrapulse frequency modulation on the VKB2445T.

2.3 PULSER REQUIREMENTS

2.3.1 DESIRED PERFORMANCE

Given that the RF rise time occurs only during 100 V region, near the peak of the grid voltage pulse, the EIA grid voltage rise and fall time could be 28 times the desired RF rise and fall time if the V_{GK} pulse rise and fall were linear. However, due to stray circuit capacitance and inductance, the rise and fall times are exponential or sinusoidal functions. Figure 2.5 is the equivalent circuit of the push-pull pulser developed for the VKB 2449T1 (had the RF-

V_{GK} characteristics been measured at the time the modulator was developed a modified pedestal approach would have been considered -- see Section 6.1). During the rise time and top of the pulse, switch S_1 is closed and S_2 is opened charging C_G toward V_o. During the fall time S_2 is closed and S_1 is opened. Thus the $R_pL_GC_G$ series circuit limits the RF rise and fall time. R_p is the planar triode plate resistance, L_G is the stray grid circuit inductance, and C_G is the combined grid circuit stray capacitance. The equivalent circuit is only approximate since the stray inductance and capacitance are distributed. The stray capacitance is approximately 40 pF and the stray inductance was measured to be 0.2 μH. If the resonant circuit is under-damped by driving the planar triode such that $R_p \simeq (4L_G/C_G)^{1/2}$, then oscillations will occur on the grid voltage pulse and a high ripple, or even a multiple pulse RF waveform, will result. This was found to be the case in the modulator developed. When S_1 was driven such that $R_p \simeq 50\ \Omega$, a 100 MHz oscillation or ringing occurred on the pulse waveform. When tested on the EIA, this resulted in a train of pulses 1 to 2 ns in width spaced in 15 to 20 ns increments. This roughly agrees with predicted behavior from the 56 MHz resonant frequency calculated from the estimated values of L_G and C_G. The short pulse RF produced by this modulation can be predicted by assuming only a single 1/2 cycle oscillation before S_2 is closed. The grid voltage near the cathode is then given by:

$$V_{GK} = -2.8\ \text{kV}\ (1 - \cos \omega t)$$

where $\omega = (L_GC_G)^{-1/2}$ and $t = 0$ is at the peak RF value at $V_{GK} = 0$. From Figure 2.3 V_{GK} at the 3 dB RF value is -100 volts, thus the 3 dB RF pulse width (t_{3dB}) is given by twice the time from 0 to the 3 dB RF point, or:

$$t_{3dB} = 1.5\ \text{ns}.$$

This result agrees with the short pulse EIA performance shown in Section 5.

The oscillations must be on the order of 50 volts to produce a long pulse. Therefore, if the circuit in Figure 2.5 is critically damped, the RF rise and fall time can be predicted by correlating the data in Figure 2.3 with the series RLC circuit solution for $V_{GK}(t)$. During the rise time, $V_{GK}(t)$ is given by:

$$V_{GK}(t) = V'_{GK} - (2.8\ KV + V'_{GK})\ \left(\frac{t}{\tau} \exp \frac{-t}{\tau}\right)$$

where

$$V'_{GK} \text{ is the peak value of } V_{GK}\ (t) \text{ and } \tau = \frac{R_p C_G}{2} = \frac{2\ L_G}{R_p}$$

Figure 2.6 is a plot of $V_{GK}(t)$ with V'_{GK} = + 50 V to allow an overshoot on $V'_{GK}(t)$ for faster RF rise time. Point A corresponds to the 10% RF power point at $V_{GK}(t)$ = -150 V and point B corresponds to the 90% RF power point at $V_{GK}(t)$ = -50 V. The RF rise time, t^+, is thus given by:

$$t^+ = t_B - t_A = 0.86.$$

For the circuit values in described in Section 2.3.1, R_p must be 141 Ω , making τ = 2.8 ns. Therefore, the RF rise time is:

$$t^+ = 2.4 \text{ ns.}$$

Figure 2.7 is a plot of the fall of $V_{GK}(t)$, again with V'_{GK} = 50 V. The fall time t^- is given by :

$$t^- = t_B - t_A = 0.16$$

or

$$t^- = .45 \text{ ns.}$$

Note that these results for the EIA are based on data from the EIO and are approximate, since the EIA does not exhibit a 10 to 15 ns turn on delay as does the EIO. However, the EIO RF fall time can be predicted by the method above.

2.3.2 PRACTICAL CONSIDERATIONS

In the actual pulser circuit, the planar triodes modeled by R_p, S_1, R_p, and S_2 are driven with a 1.5 ns pulse rise time which must be considered. In addition, due to the planar triode grid power limitations and problems in matching the planar triode drive circuit to the planar triode input, a constant saturated plate resistance R_p could not be achieved.

The rise time can be improved in the case of a short pulse spike for the EIA. The pulser dc supply voltage V_0 can be raised, effectively charging C_G toward a potential much more positive than $V_{GK} = 0$. This has the effect of making $V_{GK}(t)$ a more linear, rather than exponential, function.

The high RF-grid voltage sensitivity which resulted in the good short pulse performance caused the long pulse performance to be less than expected as a result of the droop in the pulser voltage. At the time the pulser design was completed, the RF behavior was not fully characterized. However, Section 6.1 discusses a floating deck pulser design which should yield both good short pulse and long pulse performance.

Since the emphasis of this program was the development of a short pulse, that the short pulse performance was optimized in lieu of the long pulse performance.

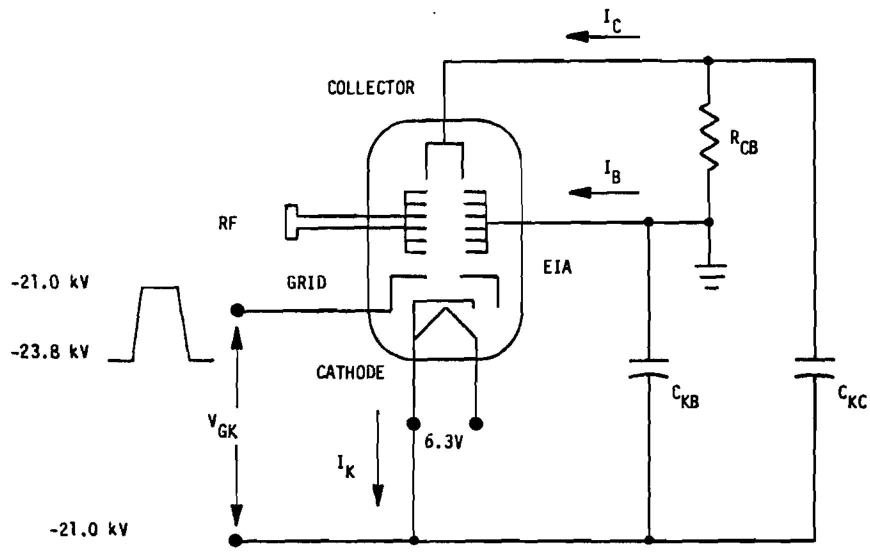

Figure 2.1. EIA voltages and currents.

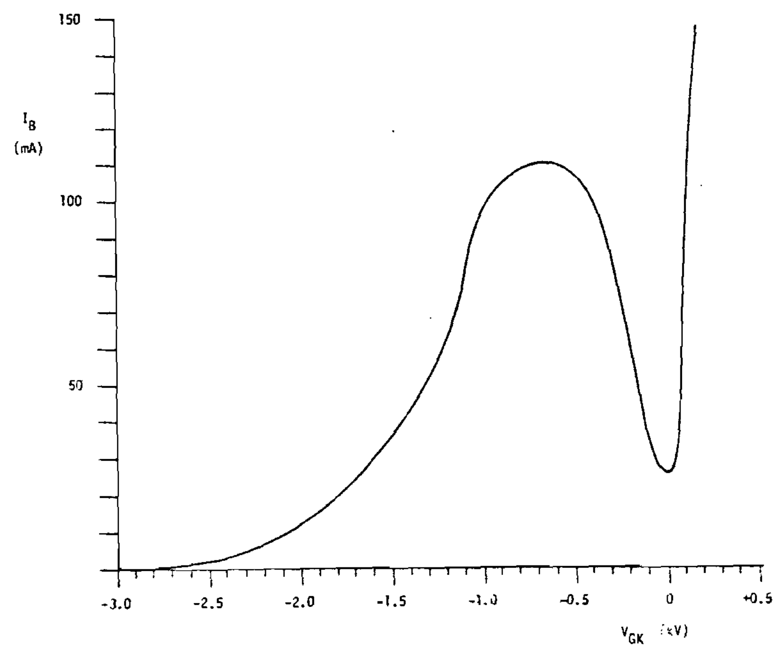

Figure 2.2. Body current vs. grid cathode voltage.

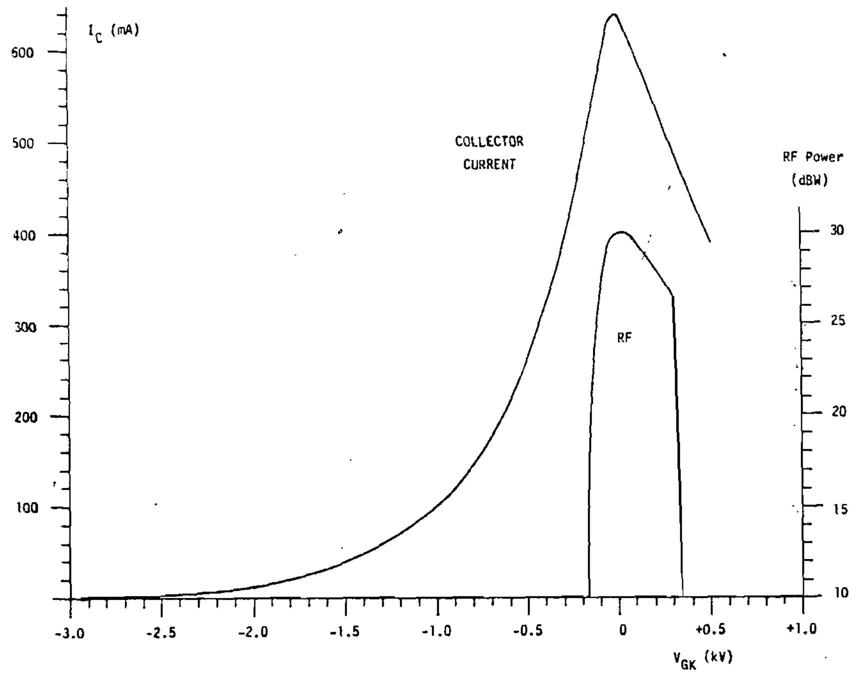

Figure 2.3. Collector current and RF power vs. grid cathode voltage.

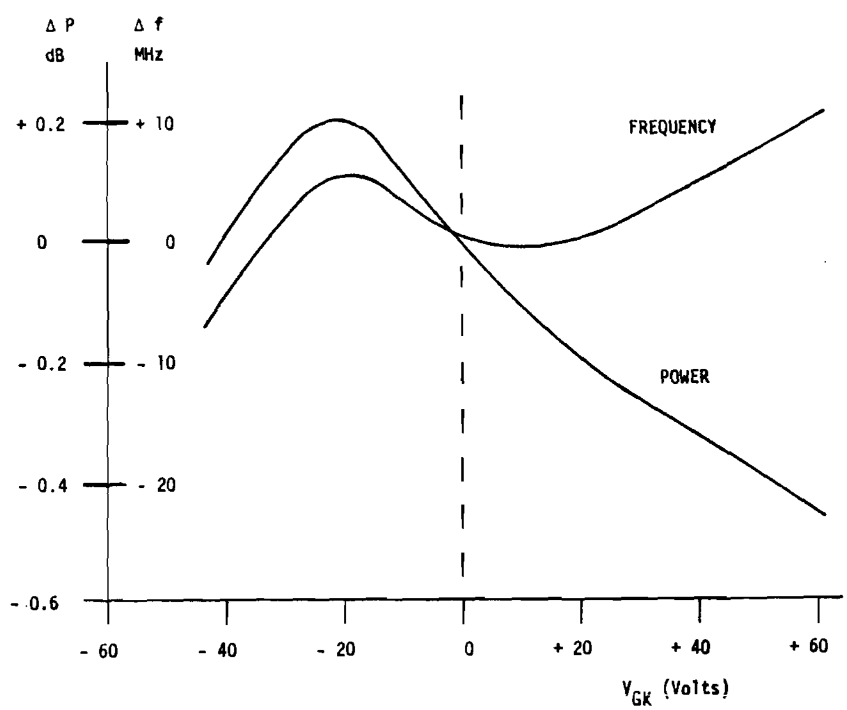

Figure 2.4. Power and frequency vs. grid-cathode voltage near cathode potential.

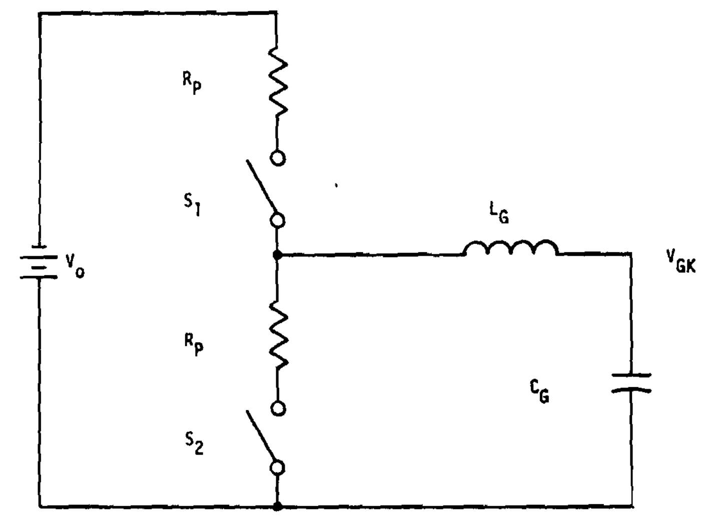

Figure 2.5. Equivalent circuit of the push-pull modulator.

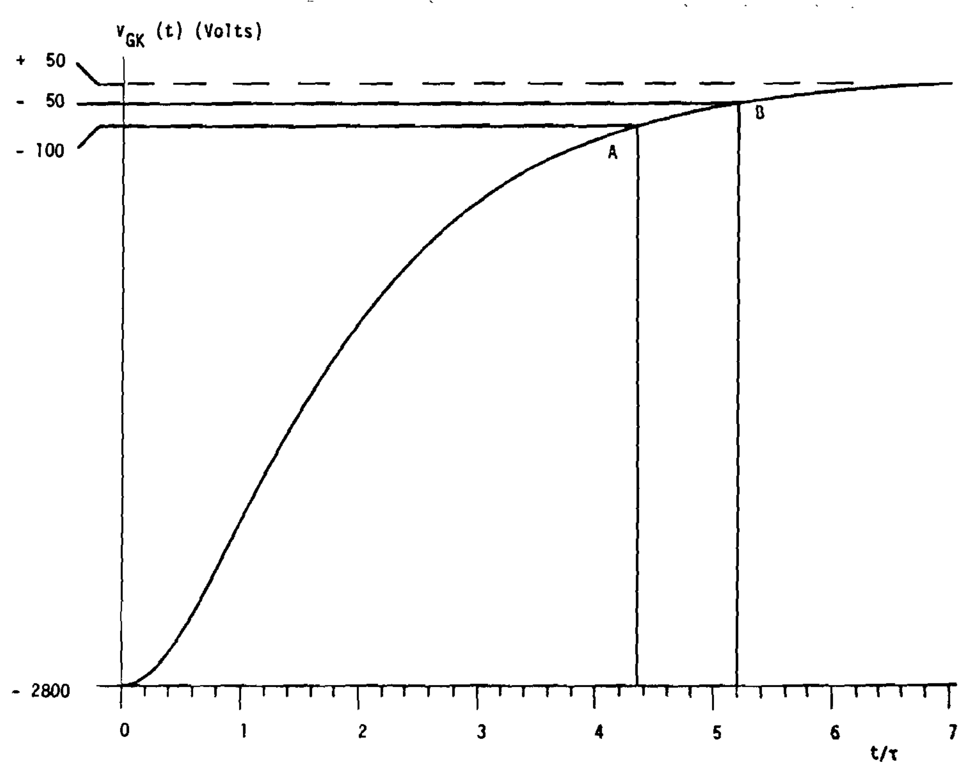

Figure 2.6. Grid-cathode voltage during the rise time - critically damped.

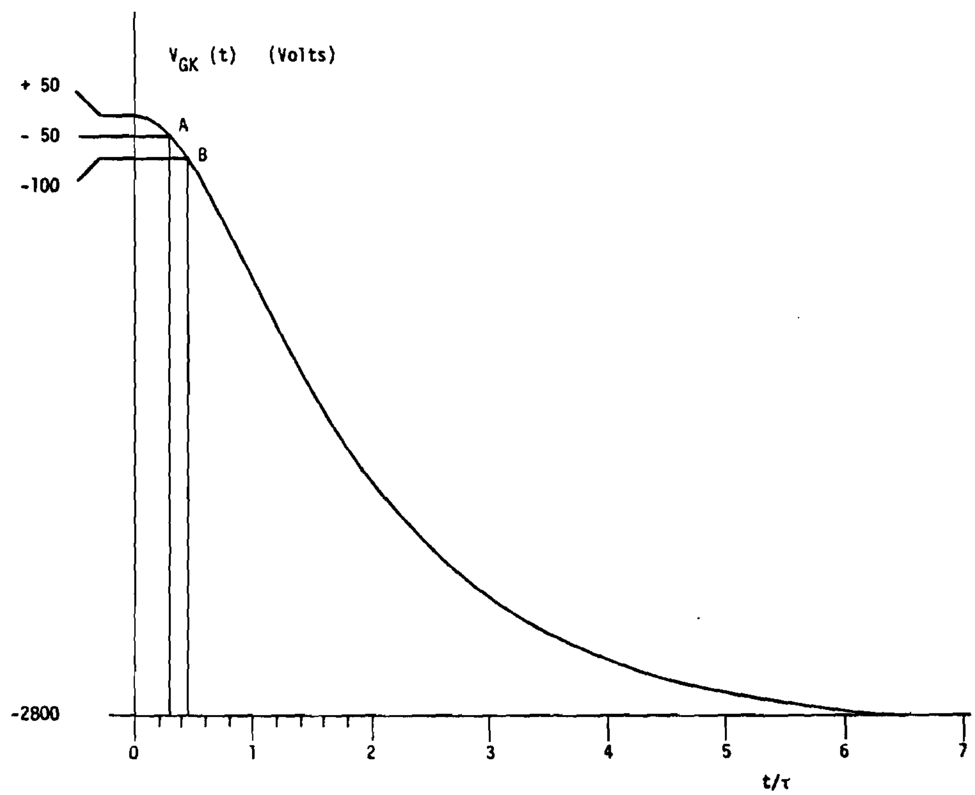

Figure 2.7. Grid-cathode voltage during fall time - critically damped.

SECTION 3
DESCRIPTION OF UNIT

3.1 PULSER/TUBE INTERFACE CIRCUIT

The simplified schematic of the grid pulser is shown in Figure 3.1. The ON PULSE, OFF PULSE 1, and OFF PULSE 2 are generated by TTL control circuits and coupled to avalanche transistors Q_1, Q_2, and Q_3 (Raytheon RS 3500). The avalanche transistors produce a 180 V transition which is used to apply the fast rise and fall times on the gates of Q_4, and Q_5, (both consisting of three IVN 6000 in parallel, and represented as a single FET on the schematic). The equivalent input capacitance of the three power FETs including Miller effect is 900 pF. This capacitance was matched to the avalanche transistor impedance by using a capacitive divider with $C_{GS} \simeq 10\ C_1 \simeq 10\ C_2 \simeq 10\ C_3$. The ON PULSE triggers Q_1 which drives the "On FETs" to saturation. This produces a negative pulse at the input of the 10 Ω transmission balun L_1. This pulse is shaped by the matching network "RC ON." The pulse is transmitted through L_1 to the cathode of V_1 which in turn is driven toward saturation, producing a positive voltage step equal to the 3 kV supply voltage.

During the top of the pulse, RC ON provides a sustaining current which feeds the magnetizing current of L_1 and L_2 (Figure 3.2). At the end of the pulse, OFF PULSE 1 fires Q_2 turning the "On FETs" off. OFF PULSE 2 fires Q_3 turning the "Off FETs" on. The "Off FETs" in turn drive V_2 through "RC OFF". The stray grid capacitance is then discharged through V_2, terminating the pulse.

The planar triodes are driven in a grounded grid circuit. This circuit has been successful in protecting the solid state drive circuit when 21 kV arcs occurred in the EIA interface circuit (Figure 3.2) coupling the 21 kV voltage through the pulser-grid coupling capacitor C_{PG}. As described in Section 2.2, C_{KC} and C_{KB} provide pulse current bypass. For a 100 ns pulse, the transmission line balun L_3 provided both collector current pulse viewing and collector body current isolation. The cathode voltage is provided by a 20 watt, -22 kV chopper-multiplier with a series pass regulator for the 28 Vdc input. The cathode supply is current limited at a value which would not damage the EIA in the event that the bias supply voltage is lowered, turning on the EIA beam. The grid bias voltage is provided by a compact 3 kV, 5 watt power supply which is floating at the cathode potential. The grid pulse is isolated through L_2. The

EIA heater and the bias supply are powered from a high voltage isolation dc-to-dc converter.

3.2 AUXILIARY CIRCUITS

3.2.1 OPERATING CONTROLS

The operating controls for the pulser are shown in Figure 3.3. The power switch provides +28 Vdc to the pulser. A yellow LED indicates when the power is on. The standby switch places the pulser in a standby condition after it has been radiating; pressing this normally closed switch deenergizes the radiate relay circuit. A green LED indicates when the time delay relay has timed out, allowing the time delay proper time for the EIA and planer triode filaments to warm up. The radiate switch, when pressed, energizes the radiate relay circuit allowing 28 Vdc to illuminate the red LED display light and activate the -22 kV high voltage power supply.

The beam voltage control sets the beam voltage on the EIA from approximately -6 kV to -23 kV. This sets the dc level of the EIA cathode to the operating value. The focus voltage control sets the voltage on the pulser high voltage power supply which adjusts the pulse potential between the grid and cathode of the EIO.

The pulse width and PRF controls allow adjustment of the RF output of the EIA. They are both incrementally adjusted by means of a digital multiplexer which selects the proper pulse width and PRF. The external position of the PRF selector switch allows an external signal generator to control the PRF. A protective circuit is included in order to prevent the PRF from exceeding 21 kHz.

3.2.2 PULSE GENERATION

The pulse is derived from an LM555 oscillator operating at 40 kHz. The oscillator output is sent to a 7493 counter to obtain signals at 20, 10, 5 and 2.5 kHz. The 20 kHz signal is sent to a 7406 inverter buffer/driver which provides a signal, both true and complement, to drive the low voltage power supply choppers. In addition to the outputs of the 7493 counter, an external PRF signal is also routed to a 74151 multiplexer which is controlled by the PRF switch. The output of the multiplexer is the PRF of the pulser. The output is then sent to a set of three one shots which control the maximum pulse width and the maximum PRF. The output of the one shots is sent to a set of delay lines and also provides a trigger output. The delay lines and buffers are used to generate the ON PULSE, OFF PULSE 1 and OFF PULSE 2. The delay between the ON PULSE and the first OFF PULSE sets the pulse width of the RF. This delay is controlled by means of another 74151 multiplexer.

3.2.3 LOW VOLTAGE POWER SUPPLIES

The filament power supply provides 6.3 V RMS to both hard tubes and the EIA plus the 28 Vdc to the floating 3 kV high voltage grid bias power supply. The 28 Vdc input is regulated by an LM 223 regulator which provides the current to two IRF 130 FETS driven by an LH 0026 line driver at 20 kHz. The two FETs are operating at 50% duty cycle, driving a ferrite power transformer in a push-pull circuit. The secondary of the transformer consists of one winding for the planar triode filaments at ground potential and high voltage insulated windings for the 28 Vdc to the 3 kV floating power supply and the filament of the EIA.

The 400/200/5 Vdc power supply consists of another chopper arrangement similar to the filament power supply. Its output transformer, however, has the secondary segmented to provide 400 Vac and 10 Vac. Approximately 400 Vdc is obtained by full-wave rectifying the 400 Vac. The 200 Vdc is obtained by a zener regulator in parallel with the 400 Vdc output. The 5 Vdc output is obtained from the output terminal of a MC7805 5V regulator whose input is obtained by full-wave rectifying the 10 Vac output of the transformer. Since the 20 kHz chopper drive input requires 5 Vdc to operate, a bootstrap circuit was added which connects the 28 Vdc directly to the input of the MC7805 regulator during the initial turn-on time. A block diagram of this circuitry is shown in Figure 3.4.

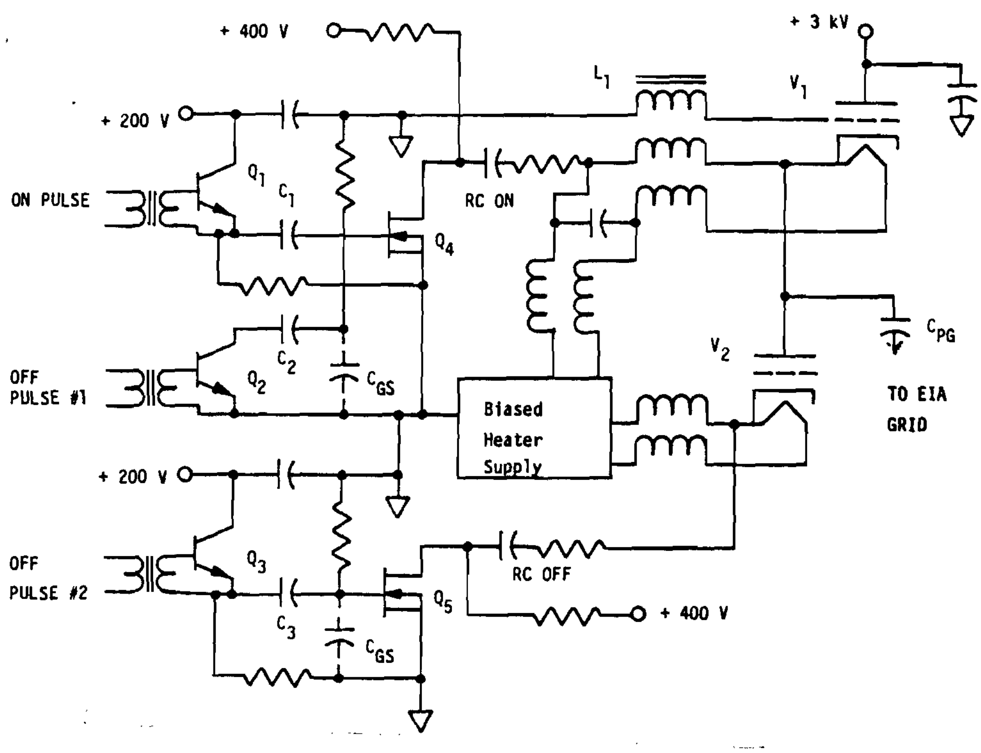

Figure 3.1. Simplified grid pulser circuit.

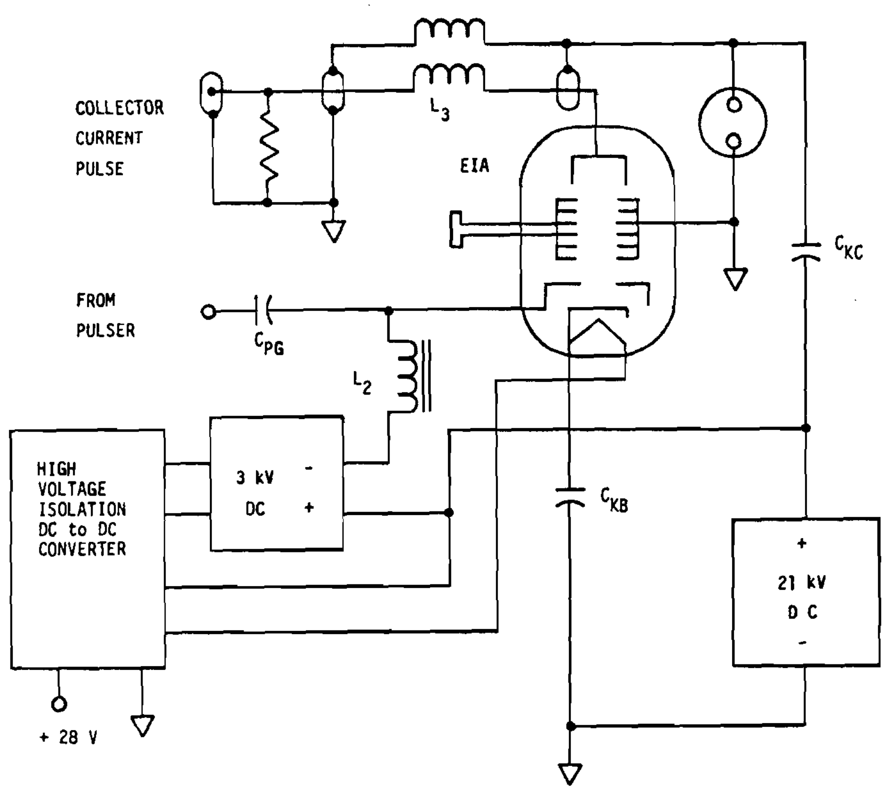

Figure 3.2. Simplified EIA interface circuit.

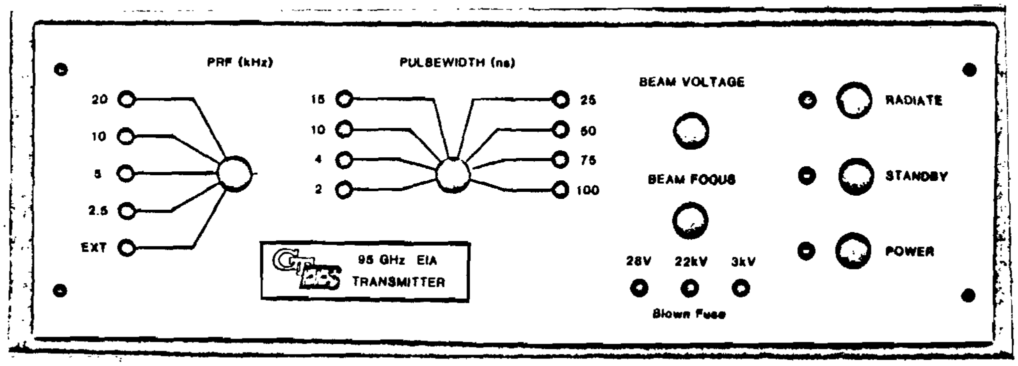

Figure 3.3. Front panel controls.

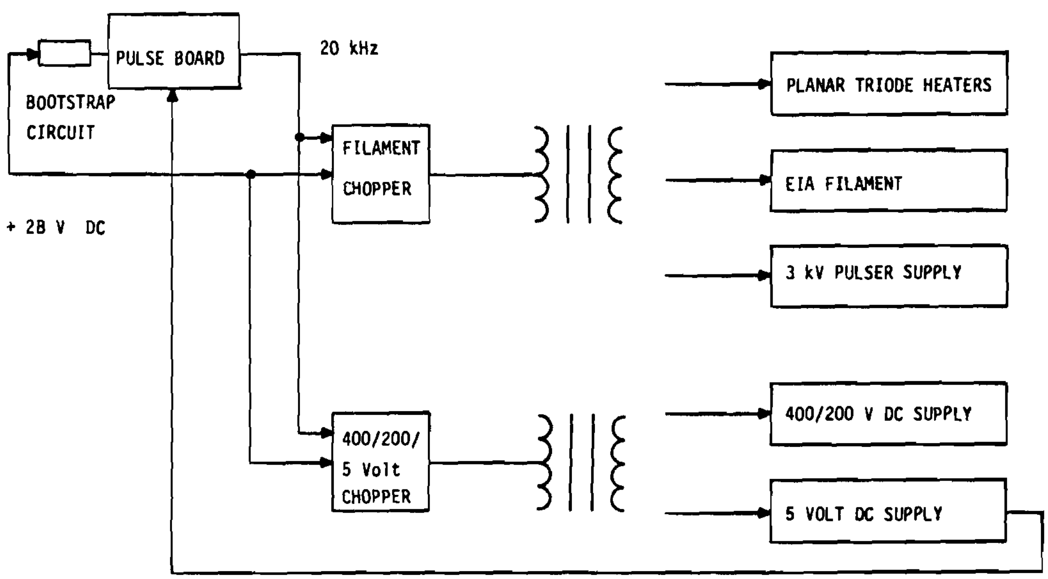

Figure 3.4. Power supply block diagram.

SECTION 4
PACKAGING AND OPERATION

4.1 DESCRIPTION

The pulser/power supply which consists of the pulser, HV power supplies, LV power supplies, pulse generator, and control circuits are packaged in a single rectangular unit designed with sufficient mechanical stability and ruggedness to support the EIA. Access to the pulser/power supply is through the top plate to which the EIA tube, switcher tubes, and main circuit are attached. Below the top plate are the power supplies and pulse control circuitry required to provide the proper voltage potentials and control.

All components that operate at -22 kV are enclosed in a 3/8 inch thick plexiglass container box, with the exception of a high voltage insulated wire which is wound around the U-core transformer. This plexiglass container is screwed together with nylon hardware, and all of its surface-to-surface gaps are filled with RTV for HV insulation. Figure 4.1 is a photograph of the pulser/power supply unit with a VKB 2445 tube attached.

4.2 TUBE MOUNTING

The top plate of the pulser must be removed to mount an EIA tube. The tube wires that connect to the three miniature pin jacks under the EIA mount should be cut as short as possible. Figure 4.2 shows a top view of the connectors for the EIA lead and indicates the proper electrode connection.

While lowering the tube into place, insert the pin at the end of the EIA high voltage lead onto its proper plug-in on the plexiglass box as indicated in Figure 4.2. Fasten the EIA onto the pulser top plate with the required hardware, and replace the top plate.

4.3 OPERATING PROCEDURE

The waveguide connections to the input and output of the EIA must be fastened properly. The input should have a source of 95 GHz RF with an isolator for protection. The output of the EIA should have a proper load capable of handling 1 kW peak power.

The 28 Vdc input power should be able to provide (as a minimum) approximately 6 amperes during turn-on. This should be connected to the screw terminals on the right side of the pulser.

Turn-on Procedure:

a. Turn beam voltage and beam focus fully counterclockwise.

b. Set PRF as required. If an EXT sync is desired, insure that the PRF of the external signal generator is less than 20 kHz; otherwise there will be no output pulse.

c. Set the pulse width as desired. If monitoring short pulses, a 100 MHz bandwidth oscilloscope is required.

d. Press the power switch. The yellow LED to its left should illuminate.

e. After approximately 2 minutes, the green LED should illuminate, indicating that all of the filaments have warmed up and the pulser is in STANDBY.

WARNING - BEWARE OF HIGH VOLTAGE

f. Monitor pulse collector current.

g. Press the RADIATE switch. The red RADIATE LED light should illuminate. Increase focus voltage and beam voltage until the collector current pulse is 600 mA.

h. RF should be present at the output of the EIA unless the beam and/or focus voltage is misadjusted.

i. Adjust the focus voltage and increase the beam voltage until the RF is maximized. Small variations in focus and beam voltage can be made to vary the shape and size of the pulse.

Photo To Be

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Figure 4.1. Pulser/power supply.

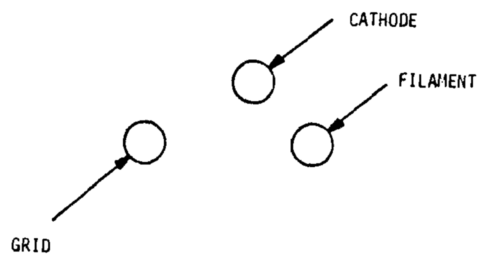

Figure 4.2. EIA connections.

SECTION 5
PERFORMANCE

The pulser was first tested on a VKB 2445T EIO provided by Varian, Canada. Injection priming was used to reduce the leading edge jitter and delay. A 95 GHz 15 mW Gunn source and high power Faraday rotational circulator were used to inject the signal into the EIO waveguide output. Figure 5.1 shows the detected RF power and collector current. Figure 5.2 shows a double exposure of the detected RF pulse with the smaller pulse attenuated 3 dB to show the 3 dB pulse width of 1.7 ns. The 1.6 ns 10% to 90% rise time and 0.9 ns fall time is shown in Figure 5.3. The long pulse performance is limited to 100 ns due to droop in the grid pulse coupling circuit and planar triode drive circuit. Figure 5.4 shows the detected RF pulse of the EIO with no priming, and Figure 5.5 shows detected RF pulse 15 mW priming.

A VKB 2449T1 EIA was available for only a few hours during which it could be used for a short pulse test. Figure 5.6 shows the detected RF pulse and collector current pulse. Figure 5.7 shows the 3 dB double exposure of the detect RF pulse. The 3 dB RF pulse width is 1.4 ns. Figure 5.8 shows a rise time of 0.68 ns and Figure 5.9 shows the fall time of 0.80 ns. The short pulse width of 3 dB agrees with the predictions in Section 2.3.1.

Slight adjustments in both the pulser 3 kV supply and the 21 kv cathode supply affect pulse shape, but the pulse shape remains stable over a 20% change in the +28 Vdc input voltage.

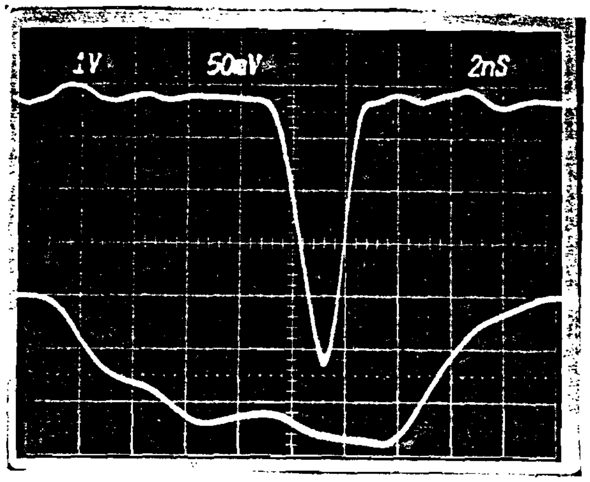

Figure 5.1. Primed EIO 1 kW detected RF and 600 mA collector current pulses.

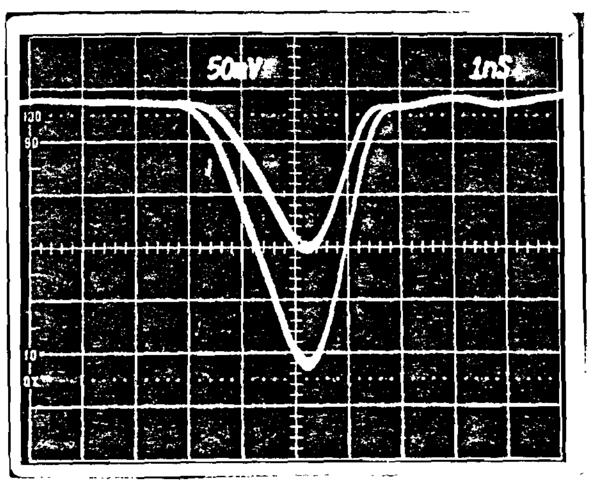

Figure 5.2. Primed EIO pulse - 1.7 ns, 3dB pulse width.

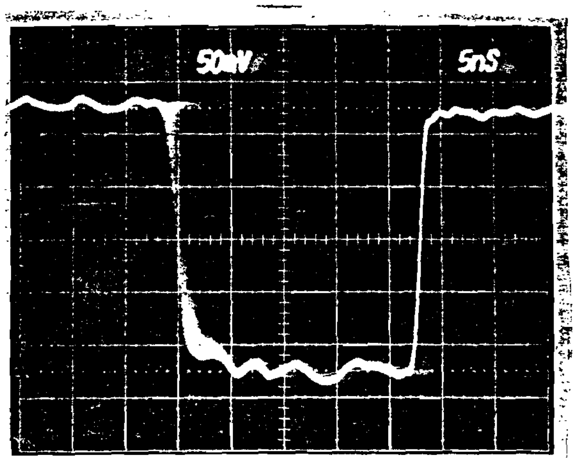

Figure 5.4. 1 kW EIO pulse, no priming.

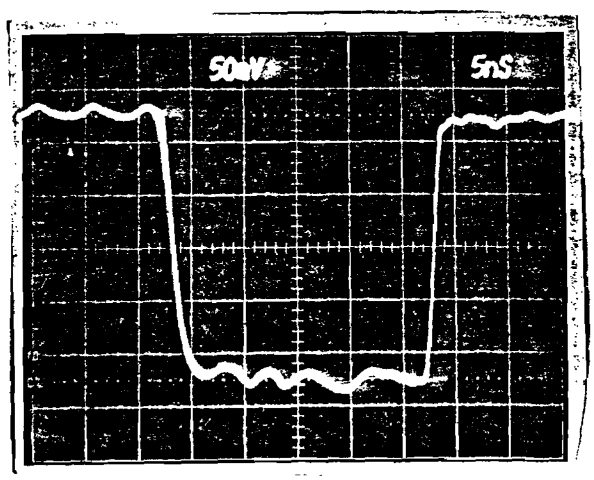

Figure 5.5. 1 kW EIO pulse, 10 mW priming.

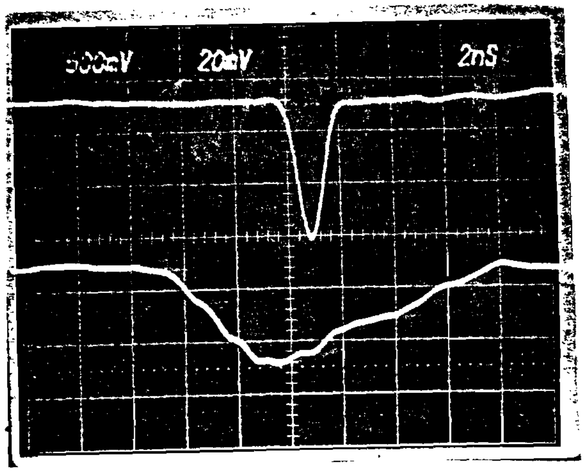

Figure 5.6. 2 kW EIA PF and 600 mA collector current pulse.

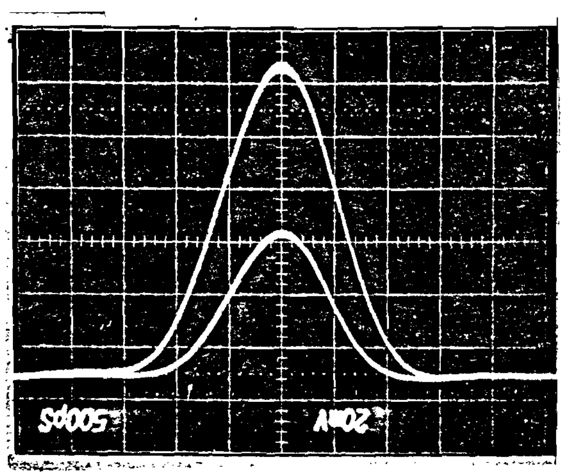

Figure 5.7. EIA 100 mW drive, 1.4 ns, 3 dB pulse width.

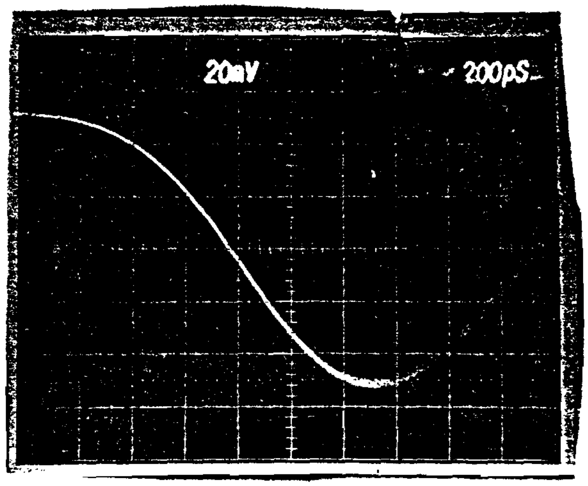

Figure 5.8. EIA .68 ns rise time.

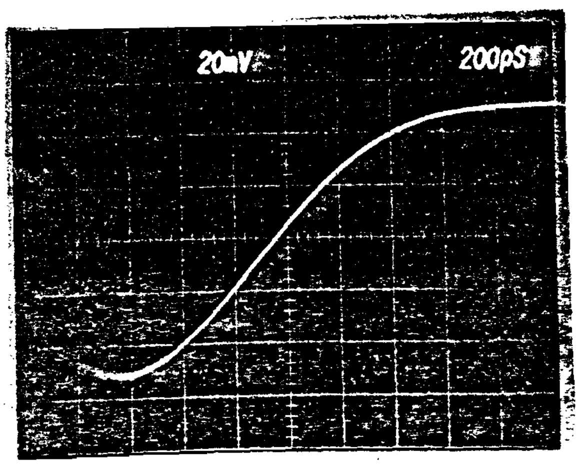

Figure 5.9. EIA .80 ns fall time.

SECTION 6
FURTHER DEVELOPMENTS

6.1 PULSER CIRCUITS

TThe grid must be effectively clamped to the cathode during the top of the pulse to achieve simultaneous long and short pulse performance. The pulser technique shown in Figure 6.1 is a floating deck pulser in which planar triode V_1 clamps the grid to the cathode. In addition, since the pulser is at the cathode potential, a physically smaller cathode grid circuit can be constructed to reduce the stray inductance. One disadvantage is that all pulser power supplies and trigger circuits must be low capacitance and must withstand 21 kV. This can be accomplished by using high frequency dc to dc converters and trigger pulse isolation transformers.

Since the RF pulse occurs only during the last few hundred volts, a pedestal pulser technique such as the circuit shown in Figure 6.2 might be developed. A solid state pulser could provide a wide pulse of relatively poor shape which would change the short pulse bypass capacitor charge to within 50 volts of the RF threshold. A short pulse could then be produced on top of this pedestal using avalanche transistors or FETs. A variety of circuits could be used to generate the pedestal. These might include: the series high voltage FETs in a push-pull circuit as shown, an FET and step-up transformer with a resistively loaded secondary, or an SCR magnetic modulator. The RF duty cycle would be limited since the EIA duty cycle is determined by the cathode current. Also the pedestal would produce a more defocused beam which could be operated only at reduced duty cycle to limit the body current to the rated value. High voltage bypass should be made to the grid as shown with the pulser enclosed in a Faraday shield and the control pulse applied to the cathode. This will reduce the possibility of discharging the beam energy through the pulser in the event of a tube arc since the gridded EIA gun is constructed with the grid surrounding the cathode, effectively extending the Farraday shield within the tube.

6.2 CONSTRUCTION TECHNIQUES

The overall size of the pulse unit can be reduced by integrating the high voltage power supplies, the low voltage power supplies, isolation supplies and control circuitry. In particular, most of the dc-to-dc converters could be consolidated into a single circuit. The physical size could also be reduced by using solid, high voltage encapsulation. A redesign of the present pulser could yield an estimated 60% to 70% volume reduction.

6.3 BONDED GRID

As the development of the focus electrode grid significantly changed the pulser design, development of the bonded grid EIO and EIA should greatly reduce the size and weight of the pulser circuit. The pulse voltage has been estimated to be only 500 volts. Such a pulser could use a power FET driven by avalanche transistors in a circuit such as the one used to drive the planar triodes.

SECTION 7
CONCLUSION

This development program has resulted in a compact pulser/power supply for the gridded EIA which is capable of operating at an RF pulse width of 1.4 ns. In addition, the gridded EIO and EIA have been characterized for short pulse operation, and useful design information has been generated which can be applied to the development of high resolution millimeter wave radar systems.

Research and Development Technical Report
DELET-TR-81-1001-F

DEVELOPMENT OF A COMPACT NANOSECOND PULSER FOR THE 95 GHz EIA

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Extended Interaction Oscillator
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A compact nanosecond pulser was developed to drive an Extended Interaction Amplifier for use as a 95 GHz RF source in a millimeter radar system.

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SECTION 1
INTRODUCTION

1.1 SCOPE

This report covers the development of a compact nanosecond pulser for the Varian Model VKB 2449T1 95 GHz extended interaction amplifier (EIA). The work was performed for the U.S. Army ERADCOM Beam, Plasma and Display Division under contract DAAK20-81-K-1001. The nanosecond pulser is required for use in all-weather RPV millimeter wave radar systems and an experimental millimeter wave radar to evaluate fixed target classification techniques. This report documents the work performed during the period from 1 June 1981 to 1 June 1982.

The primary objective of this program was the development of a pulser for the 95 GHz EIA which would be capable of producing pulses with extremely narrow pulse width and high pulse repetition frequency. A further concern was to determine and execute the optimum design approach in terms of size, weight, life, reliability, circuit simplicity, and maintainability. The results of this program may well lead to the development of pulsers for use in airborne high resolution radar systems.

A second objective was to characterize the behavior of the EIA, particularly for short pulse widths. Although no model VKB 2449T1 EIA could be furnished for characterization, an effort was made to predict the behavior of the EIA from the data and experience gained in operating various other Varian extended interaction devices. The predictions can be tested when a VKB 2449T1 can be made available.

A third objective was to determine other design approaches which might yield better overall performance in specific applications and to suggest areas of improvement in the design that was developed.

1.2 SUMMARY

The nanosecond pulser developed under this program is capable of charging and discharging the capacitance of the EIA grid with sufficient speed to assure nanosecond pulsing by using an on/off switching technique. This technique employs planar triodes, power MOS FETs, and avalanche transistors in a push-pull circuit. Consideration was given to preserving the fast rise time properties of the pulse circuit by minimizing stray capacitance and inductance.

The pulser unit includes (1) power supplies, (2) modulator, and (3) trigger and control circuitry. The tube is protected by current-limited, high voltage power supplies and low energy storage in the high voltage coupling and bypass circuitry.

Table 1 lists the specific requirements for the nanosecond pulser and the actual performance achieved or demonstrated in the unit developed. These requirements were based on the operating characteristics of the cathode pulsed EIA VKB 2400T. They were amended later for the VKB 2449T1 focus electrode controlled (FEC) EIA before this tube had been fully characterized for both short and long pulse behavior. The original design approach could not give both long pulses and short pulses. Therefore, the pulser design was optimized for best short pulse performance. This design resulted in a much shorter pulse width than thought possible. Although the long pulse width goal was not achieved with the unit developed, Section 6.1 gives a pulser design approach which should yield both good long pulse and short pulse performance.

TABLE 1. NANOSECOND MODULATOR SPECIFICATIONS FOR EIA TUBE MODEL VKB 2449T1

Specific Requirements	Goal	Performance Achieved
Peak power	1 kW	1 kW
Peak pulse voltage	3 kV	3 kV
Peak cathode current	1 A	1 A
PRF	20 kHz	20 kHz
RF pulse width (50%)	4 ns to 500 ns	1.4 ns to 100 ns
RF rise & fall time (10% to 90%)	2 ns max	.8 ns
Volume (modulator)	3 liters max	N/A
Weight (modulator)	2.5 kgm max	N/A

TABLE 1. NANOSECOND MODULATOR SPECIFICATIONS FOR EIA TUBE MODEL VKB 2449T1 (CONTINUED)

Specific Requirements	Goal	Performance Achieved
Volume (modulator plus power supplies & trigger)	4.0 liters max	11 liters
Weight (modulator plus power supplies & trigger)	3.5 kgm max	5 kgm
MTBF	1000 hrs min	Undetermined
Jitter	0.5 ns max	0.1 ns
Input voltage	28 Vdc	28 Vdc
Phase variation	4°	Undetermined

SECTION 2
EIA OPERATING CHARACTERISTICS

2.1 BACKGROUND

The investigation of the operating characteristics of the extended interaction amplifier began with earlier investigations of the extended interaction oscillator (EIO). The EIO was first developed as a CW oscillator in the early 1970s. In 1978, the EIO was modified to produce high peak power pulses at millimeter wavelengths. Since that time, the EIO has become the most widely used high power tube in instrumentation and developmental millimeter wave radar transmitters, including 13 units developed at Georgia Tech. This cathode pulsed EIO is operated by applying a -13 kV pulse to the cathode which is biased at the dc anode potential of -8 kV for a total beam voltage of -21 kV.[1] Observations have shown that the RF produced by the cathode pulsed EIO is delayed from the voltage pulse and "snaps on" with a rise time on the order of one nanosecond.[2]

In 1981, Varian developed the nonintercepting focus electrode or "gridded" electron gun which allows the EIO or EIA to be operated in the manner of a conventional grid modulated TWT. The cathode is operated at -21 kV dc and the beam is cut off with -2.8 kV on the grid with respect to the cathode. The focus electrode controlled gun has been used in both the EIO and the EIA. As expected, the delay and "snap on" RF behavior also occurs in the gridded EIO, since the delay and "snap on" is the result of the exponential building of the RF oscillation from the noise level in the oscillator. In a test conducted at Varian, Canada, on the first gridded EIO, a nanosecond pulse capability was demonstrated using the technique of injec-

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[1] Ewell, G.W., Ladd, D.S., and Butterworth, J.C., "Operation of Pulsed Millimeter Wavelength Extended Interaction Oscillators," Proceedings IEEE/MTT-S Symposium, May 1979.

[2] Ladd, D.S. and Butterworth, J.C., "Design Criteria for Compact Nanosecond Modulators for EIO's and EIA's," Final Technical Report, Contract DAAG29-76-D-0100, Georgia Tech, October 1980.

tion priming.[3] Further tests demonstrated that the EIO output was coherent with the injected RF signal. This indicated that the EIO could be injection locked.[4] In addition, one of the first cathode pulsed EIA's was tested and observed to have discernible delay between the beam current pulse and the RF pulse. Further experimentation with "gridded" EIA's did not indicate any discernible "snap on" RF behavior.

2.2 APPLICABLE EIO CHARACTERISTICS

The function of the pulser/power supply is to apply the required dc and pulsed voltage waveforms to the electrodes of the RF transmitting tube which will result in the desired RF pulse performance. Accomplishment of desired RF pulse performance requires determination of the exact relationship between the RF pulse power, the RF phase or frequency, and the electrode pulse voltages.

At the time the pulser was developed, the RF voltage characterization for the VKB 2449T1 EIA had not been accomplished. This tube was available for only a few hours during which only the short pulse test could be performed. Therefore, the characteristics of the VKB 2449T1 EIA are inferred from the data taken on the VKB 2445T EIO. During the short pulse test, the gridded EIA was observed to behave in a manner consistent with the predictions based on the data from the gridded EIO, except that there was no discernible delay between the collector current pulse and the RF pulse.

Figure 1 shows the EIA pulse and dc voltages and currents in a pulsed, suppressed collector circuit. The grid of the EIA is biased at -2.8 kV with respect to the cathode during the interpulse period. During the pulse rise time, most of the beam current is intercepted by the body. As the grid voltage approaches -21 kV, i.e., the dc cathode potential, the electron beam

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[3] Ladd, D.S., Conrad, G.M. and Butterworth, J.C., "Design Criteria for Compact Nanosecond Modulators for Gridded EIO's and EIA's," Final Technical Report, Contract DAAG29-76-D-0100, Georgia Tech, June 1981.

[4] Ladd, D.S., "Nanosecond Behavior of Extended Interaction Oscillators," Proceedings Tri-Service Radar Symposium, October 1981.

is focused through the slow wave structure, or body, and intercepted by the collector. Beam transmissions of 97% have been achieved in the 95 GHz EIO.

Capacitors C_{KB} and C_{KC} provide the pulse current bypass for the cathode and collector. The use of this circuit allows low energy storage in the power supply with low droop on the cathode voltage which has a high voltage-phase or voltage-frequency pushing figure. Resistor R_{CB} isolates the collector pulse current I_C from the body, causing I_C to flow back to the cathode through C_{KC}. The result is that the voltage droop due to I_C appears from the collector to body since only the body current, I_B, flows through C_{KB}. Care must be taken to prevent the peak collector voltage from exceeding the rated value.

A typical plot of the EIO or EIA body intercept current (I_B) as a function of the grid-cathode voltage (V_{GK}) is found in Figure 2. The focusing of the beam through the interaction region is shown by the null at $V_{GK} = 0$ volts.

The relationship between the RF power, the collector current I_C, and V_{GK} is shown in Figure 3 for an EIO. Note that the RF rise time from 20 dBW to 29.5 dBW (approximately 10% to 90%) occurs between $V_{GK} = -150$ V and $V_{GK} = -50$ V, which is only 100 V out of the 2.8 kV swing of V_{GK}. In later discussions it will be shown that this high RF-voltage sensitivity has permitted the successful nanosecond operation of both the EIA and the EIO.

Figure 4 shows the sensitivity of the EIO RF power and frequency as a function of V_{GK} in the -60 V to +60 V range. Note that both the RF power and frequency are strongly affected by small changes in V_{GK}. For applications requiring high frequency and power stability, the peak grid voltage must have very low droop and ripple across the top of the pulse. In most cases, this is on the order of one percent or less of the pulse voltage. A combined ripple and droop of less than 10 V has been demonstrated by measurement of the intrapulse frequency modulation on the VKB 2445T EIO.

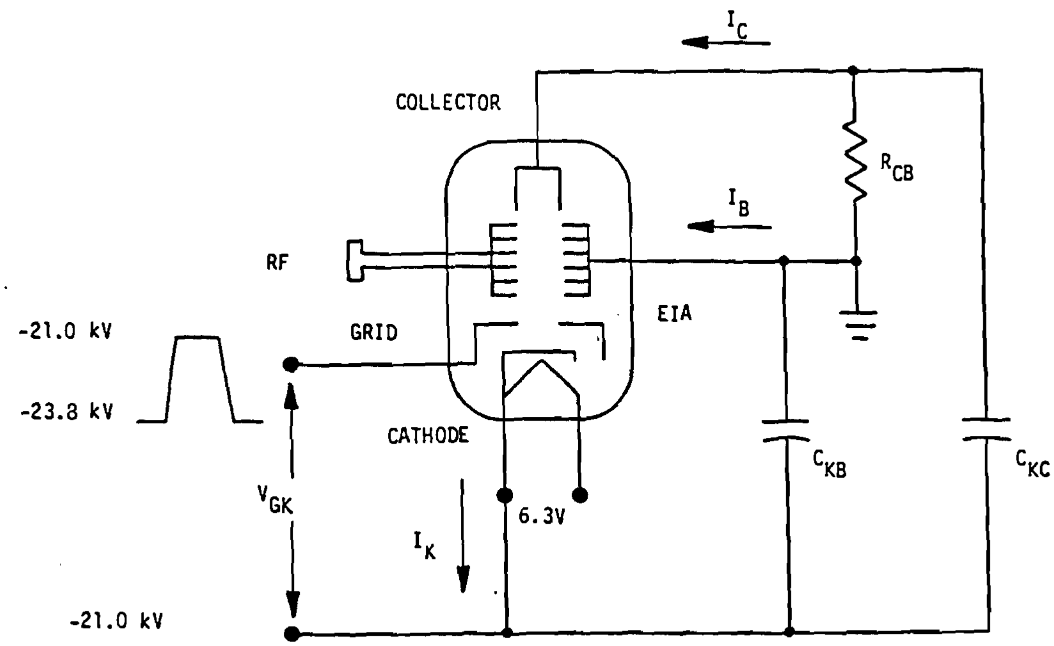


Figure 1. EIA voltages and currents.

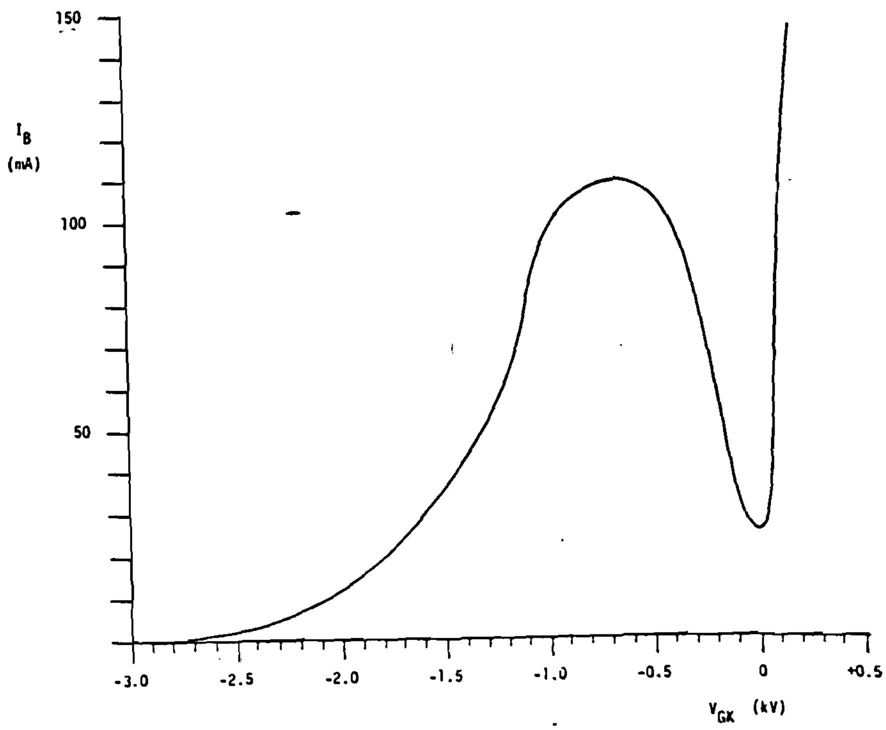


Figure 2. Body current vs. grid-cathode voltage.

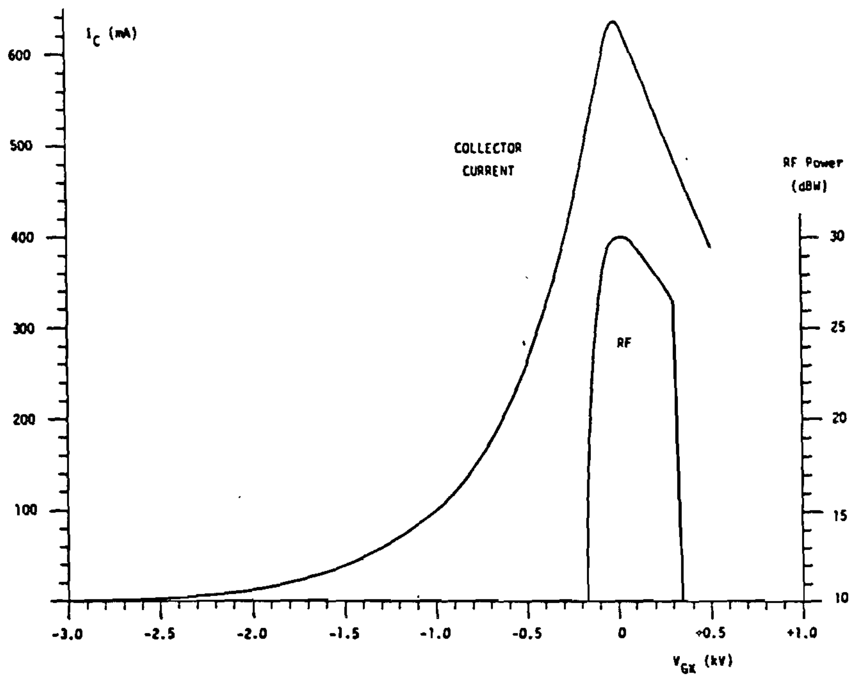


Figure 3. Collector current and RF power vs. grid-cathode voltage determined experimentally on VKB 2445T EIO.

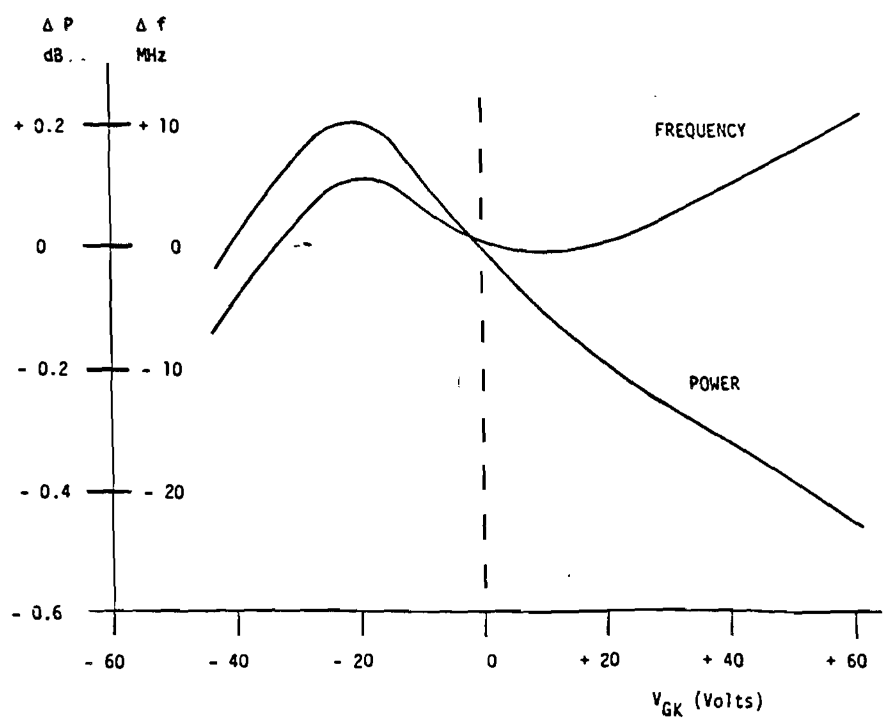


Figure 4. Power and frequency vs. grid-cathode voltage near cathode potential determined experimentally on VKB 2445T EIO.

2.3 PULSER REQUIREMENTS

2.3.1 DESIRED PERFORMANCE

As described in Figure 3, the RF rise time and fall time for an EIO occurs only in the -100 V region of V_{GK}, near the peak of the grid voltage pulse. By roughly attributing similar performance to an EIA and assuming that the rise and fall times are linear functions of V_{GK} (the grid voltage), V_{GK} rise and fall times could be 28 times the desired RF rise and fall times. However, due to stray circuit capacitance and series inductance, the rise and fall times are exponential or sinusoidal functions.

Figure 5 is the equivalent circuit of the push-pull pulser developed for the VKB 2449T1 (had the RF-V_{GK} characteristics been known at the time the modulator was developed, a modified pedestal approach would have been considered -- see Section 6.1). During the rise time and top of the pulse, switch S_1 is closed and S_2 is opened, charging C_G toward V_o. During the fall time, S_2 is closed and S_1 is opened. Thus, the $R_pL_GC_G$ series circuit limits the RF rise and fall time. R_p is the planar triode plate resistance, L_G is the stray grid circuit inductance, and C_G is the combined grid circuit and stray capacitance. The equivalent circuit is only approximate since the stray inductance and capacitance are distributed. The capacitance, C_G, is approximately 40 pF, and the stray inductance was measured to be 0.2 μH.

If the resonant circuit is under-damped by driving the planar triode such that $R_p \simeq (4L_G/C_G)^{1/2}$, then oscillations and a high ripple will occur on the grid voltage pulse, and a multiple pulse RF waveform could result. This was found to be the case in the modulator developed. With S_1 closed and $R_p \simeq 150\,\Omega$, a 100 MHz oscillation or ringing occurred on the EIA grid pulse waveform. When tested on the EIA, this resulted in a train of pulses 1 to 2 ns in width spaced in 15 to 20 ns increments. This roughly agrees with behavior predicted from the 56 MHz resonant frequency resulting from the estimated values of L_G and C_G. The short pulse RF produced by this modulation can be predicted by assuming only a single 1/2 cycle oscillation before S_2 is closed.

From Figure 3, V_{GK} is approximately -100 volts when the RF power is 3 dB below its peak value. The 3 dB RF pulse width (t_{3dB}) is given by twice the time required for the RF pulse to change from its peak value to the 3 dB value. The 3 dB RF pulse width for the EIA was measured to be equal to

$$t_{3dB} = 1.5 \text{ ns}.$$

Figure 6 is a plot of $V_{GK}(t)$ with the peak V_{GK} = + 50 V to allow an overshoot on $V_{GK}(t)$ for faster RF rise time. Point A corresponds to the 10% RF power point at $V_{GK}(t)$ = -100 V and point B corresponds to the 90% RF power point at $V_{GK}(t)$ = -50 V. The RF rise time can be derived from

$$\left(\frac{t}{\tau}\right)_B - \left(\frac{t}{\tau}\right)_A = 0.86.$$

For the values of R_P and C_G described earlier and assuming a critically damped condition, $\tau = (R_P\ C_G)/2 = 3$ ns. Therefore, the RF rise time is

$$t^{+} = 2.6 \text{ ns}.$$

Figure 7 is a plot of the fall of $V_{GK}(t)$, again with the peak V_{GK} = + 50 V. The fall time can be derived from

$$\left(\frac{t}{\tau}\right)_B - \left(\frac{t}{\tau}\right)_A = 0.16$$

or

$$t^{-} = .48 \text{ ns}.$$

Note that these results for the EIA are based on data from the EIO and are approximate, since the EIA does not exhibit a 10 to 15 ns turn on delay as does the EIO. However, the EIA RF fall time can be predicted by the method above if the RF sensitivity to the grid to cathode voltage, V_{GK}, is similar and a critically damped network is used to drive it.

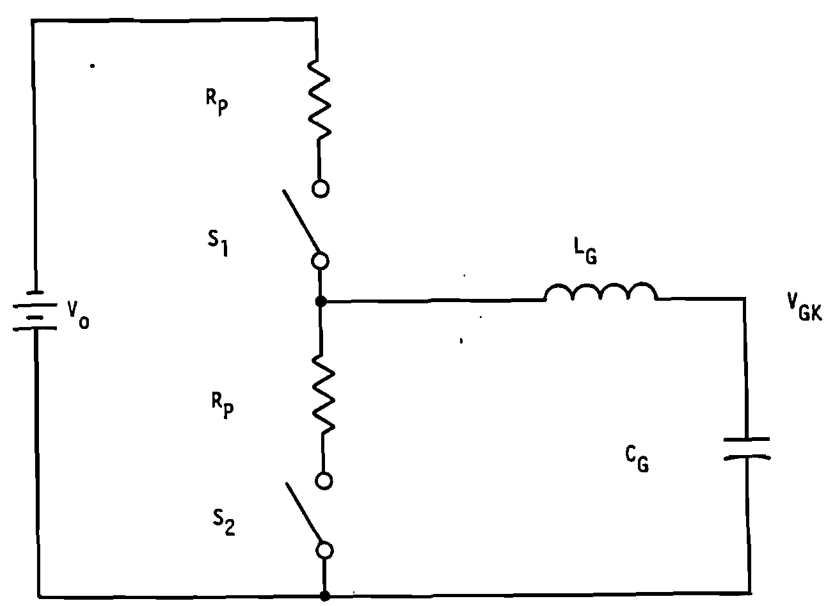


Figure 5. Equivalent circuit of the push-pull modulator.

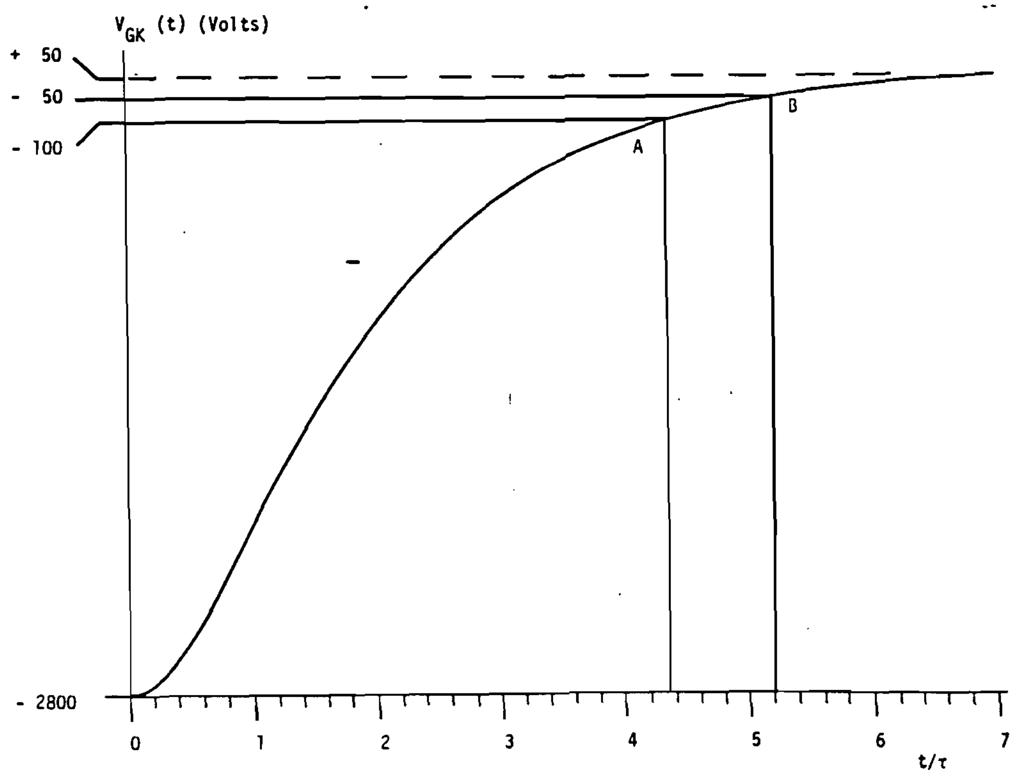


Figure 6. Grid-cathode voltage during the rise time - critically damped.

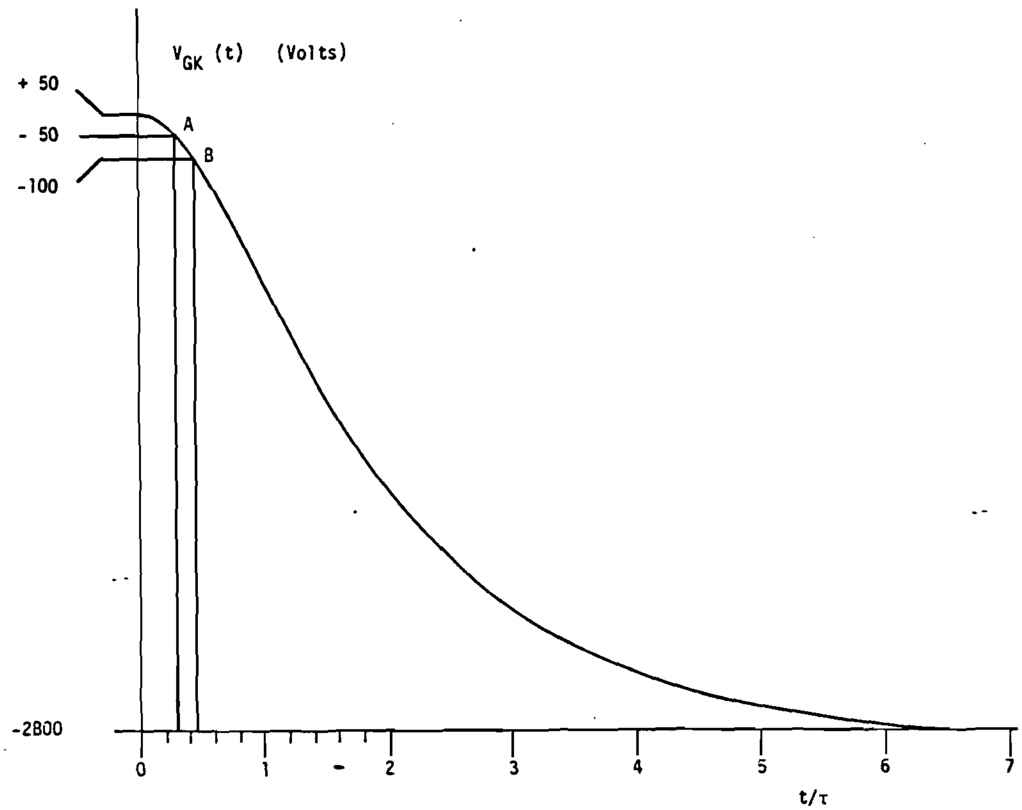


Figure 7. Grid-cathode voltage during fall time - critically damped.

2.3.2 PRACTICAL CONSIDERATIONS

In the actual pulser circuit, the planar triodes modeled by R_p, S_1, R_p, and S_2 are driven by a pulse having a 1.5 ns rise time. In addition, due to the planar triode grid power limitations and problems in matching the planar triode drive circuit to the planar triode input, a constant saturated plate resistance R_p could not be achieved.

The rise time can be improved in the case of a short pulse spike for the EIA. The pulser dc supply voltage V_o can be raised, effectively charging C_G toward a potential much more positive than $V_{GK} = 0$. This has the effect of making $V_{GK}(t)$ a more linear, rather than exponential, function.

The high EIA RF frequency and power to grid voltage sensitivity, which resulted in the good short pulse performance, caused the long pulse performance to be less than expected as a result of the droop in the pulser voltage. At the time the pulser design was completed, the RF behavior of the EIA was not fully characterized. However, Section 6.1 discusses a floating deck pulser design which should yield both good short pulse and long pulse performance. Since the emphasis of this program was the development of a short pulse, the short pulse performance was optimized in lieu of the long pulse performance.

SECTION 3
DESCRIPTION OF UNIT

3.1 PULSER/TUBE INTERFACE CIRCUIT

The simplified schematic of the grid pulser is shown in Figure 8. The detailed circuit schematic and the parts list are located in Appendices A and B, respectively. The ON PULSE, OFF PULSE #1, and OFF PULSE #2 are generated by TTL control circuits and coupled to avalanche transistors Q_1, Q_2, and Q_3 (Raytheon RS 3500). The avalanche transistors produce a 180 V transition which is used to apply the fast rise and fall times on the gates of Q_4 and Q_5 (both consisting of three IVN 6000 in parallel, but represented as a single FET on the simplified schematic). Product specification sheets for the RS 3500 and IVN 6000 are included in Appendix C. The equivalent input capacitance of the three power FETs including Miller effect is approximately 900 pF. This capacitance is matched to the avalanche transistor impedance by using a capacitive divider with $C_{GS} \approx 10C_1 \approx 10C_2 \approx 10C_3$. The ON PULSE triggers Q_1 which drives the "On FETs" to saturation. This produces a negative pulse at the input of the 10 Ω transmission line L_1. The pulse is transmitted through L_1 to the cathode of V_1 which in turn is driven toward saturation, producing a positive voltage step at the cathode of V1 and plate of V2. This pulse is coupled through C_{P_G} to the EIA grid.

During the top of the pulse, RC ON provides a sustaining current which feeds the magnetizing current of L_1 and L_2 (Figure 8). At the end of the pulse, OFF PULSE #1 fires Q_2 turning the "On FETs" off. OFF PULSE #2 fires Q_3 turning the "Off FETs" on. The "Off FETs" in turn drive V_2 through "RC OFF." The EIA stray and grid capacitance is then discharged through V_2, terminating the pulse.

The planar triodes are driven in a grounded grid circuit. This circuit has been successful in protecting the solid state drive circuit when 21 kV arcs occurred in the EIA interface circuit (Figure 9) coupling the 21 kV voltage through the pulser-grid coupling capacitor C_{PG}. As described in Section 2.2, C_{KC} and C_{KB} provide pulse current bypass. The cathode voltage is provided by a 15 watt, -22 kV chopper-multiplier with a series pass regu-

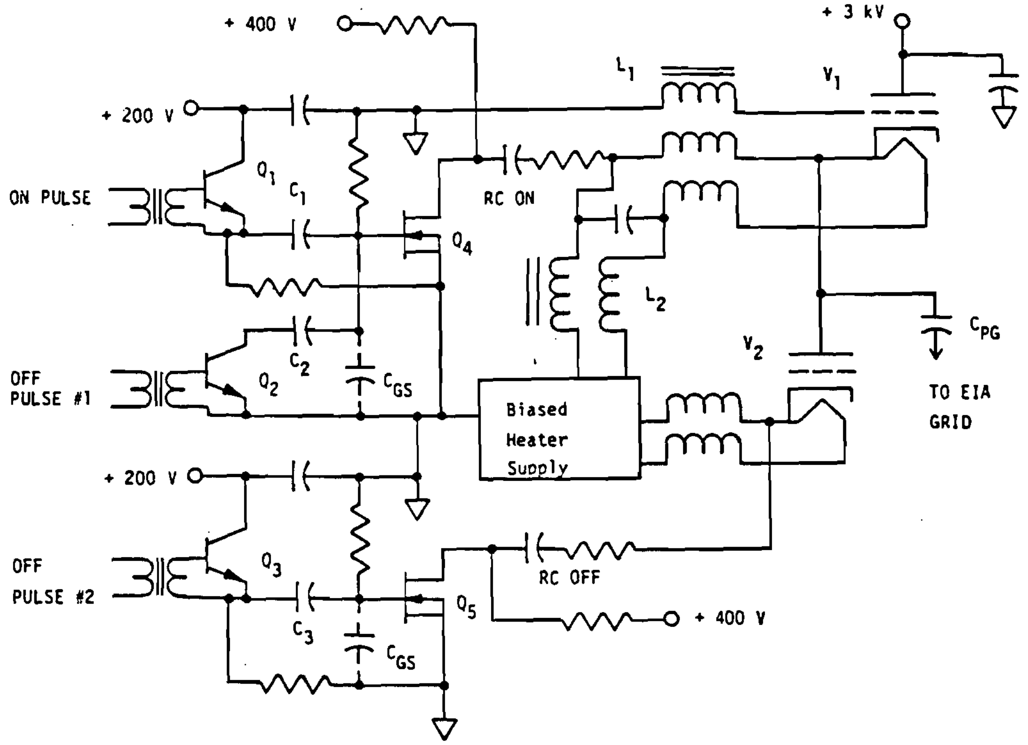


Figure 8. Simplified grid pulser circuit.

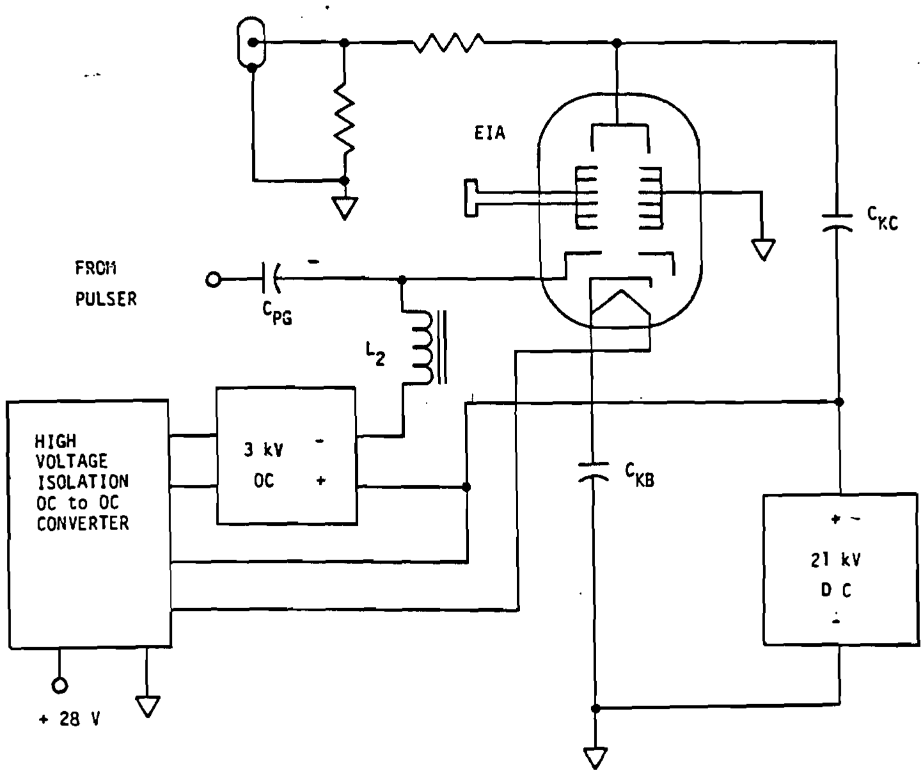


Figure 9. Simplified EIA interface circuit.

lator for the 28 Vdc input. The cathode supply is current limited at a value which would not damage the EIA in the event that the bias supply voltage is lowered, turning on the EIA beam. The grid bias voltage is provided by a compact 3 kV, 5 watt power supply which floats at the cathode potential. The grid pulse is isolated from the 3 kV supply by L_2. The EIA heater and the bias supply are powered from a high voltage isolation dc-to-dc converter. Manufacturer's specification sheets on all high voltage power supplies used are located in Appendix C.

3.2 AUXILIARY CIRCUITS

3.2.1 OPERATING CONTROLS

The operating controls for the pulser are shown in Figure 10. The schematic diagram for the control and power circuitry is located in Appendix A. The POWER switch provides +28 Vdc to the pulser. A yellow LED illuminates when the power is on. The STANDBY switch places the pulser in a standby condition after it has been radiating; pressing this normally closed switch deenergizes the radiate relay circuit. A green LED illuminates when the time delay relay has timed out, allowing proper time for the EIA and planar triode filaments to warm up. When depressed, the RADIATE switch energizes the radiate relay circuit, allowing 28 Vdc to illuminate the red LED display light and activate the -22 kV high voltage power supply.

The BEAM VOLTAGE control is used to adjust the EIA beam voltage over the range of approximately -6 kV to -23 kV. This sets the dc level of the EIA cathode to the operating value. The BEAM FOCUS control is used to set the voltage of the pulser high voltage power supply (3 kV) so that the potential between the grid and cathode of the EIO is zero during the top of the grid pulse.

The PULSEWIDTH (ns) and PRF (kHz) controls allow adjustment of the RF output of the EIA. These controls program a digital multiplexer which selects the proper pulse width and PRF. The EXT position of the PRF (kHz) selector switch allows an external signal generator to control the PRF. A protective circuit is included to prevent the PRF from exceeding 21 kHz.

3.2.2 PULSE GENERATION

The schematic diagram for the pulse control circuitry is located in Appendix A. The pulse is derived from an LM555 oscillator operating at 40 kHz. The oscillator output is sent to a 7493 counter to obtain signals at 20, 10, 5 and 2.5 kHz. The 20 kHz signal is sent to a 7406 inverter buffer/driver which provides a signal, both true and complement, to drive the low voltage power supply choppers. In addition to the outputs of the 7493 counter, an external PRF signal is also routed to a 74151 multiplexer which is controlled by the PRF switch. The output of the multiplexer is the PRF of the pulser. The output is then sent to a set of three one shots which control the maximum pulse width and the maximum PRF. The output of the one shots is sent to a set of delay lines and also provides a trigger output. The delay lines and buffers are used to generate the ON PULSE, OFF PULSE #1 and OFF PULSE #2. The delay between the ON PULSE and OFF PULSE #1 sets the pulse width of the RF. This delay is controlled by means of another 74151 multiplexer.

3.2.3 LOW VOLTAGE POWER SUPPLIES

A block diagram of the low voltage power supply system is shown in Figure 11. The filament power supply, illustrated in Appendix A, provides 6.3 V RMS to the planar triodes and the EIA, plus the 28 Vdc to the floating 3 kV high voltage grid bias power supply. The 28 Vdc input is regulated by an LM 223 regulator which provides the current to two IRF 130 FETs driven by an MMH0026 line driver at 20 kHz. The two FETs operate at a 50% duty cycle, and drive a ferrite power transformer in a push-pull circuit. The secondary of the transformer consists of one winding for the planar triode filaments at ground potential, and high voltage insulated windings for the filament of the EIA and the 28 Vdc to the 3 kV floating power supply.

The schematic diagram for the 400/200/5 Vdc power supply is located in Appendix A. This power supply consists of another chopper arrangement similar to the filament power supply. Its output transformer, however, has the secondary segmented to provide approximately 400 Vdc and 10 Vdc by full-

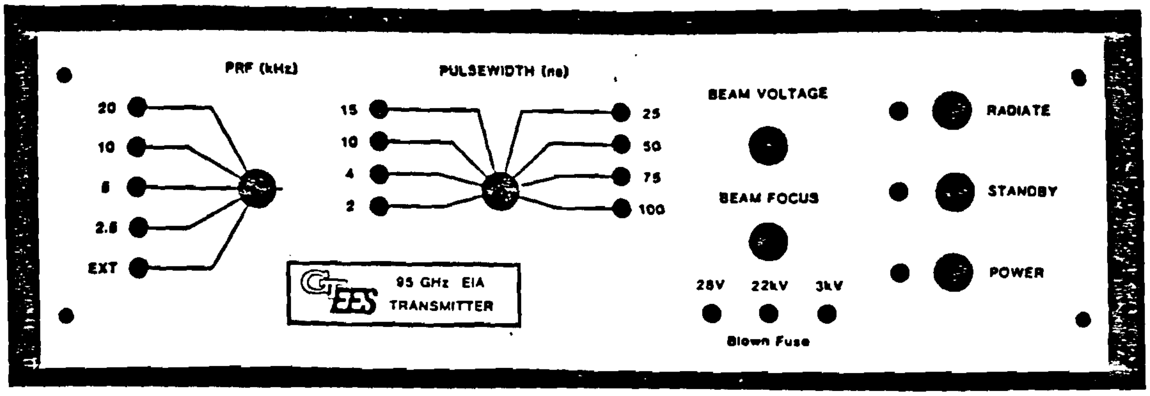


Figure 10. Front panel controls.

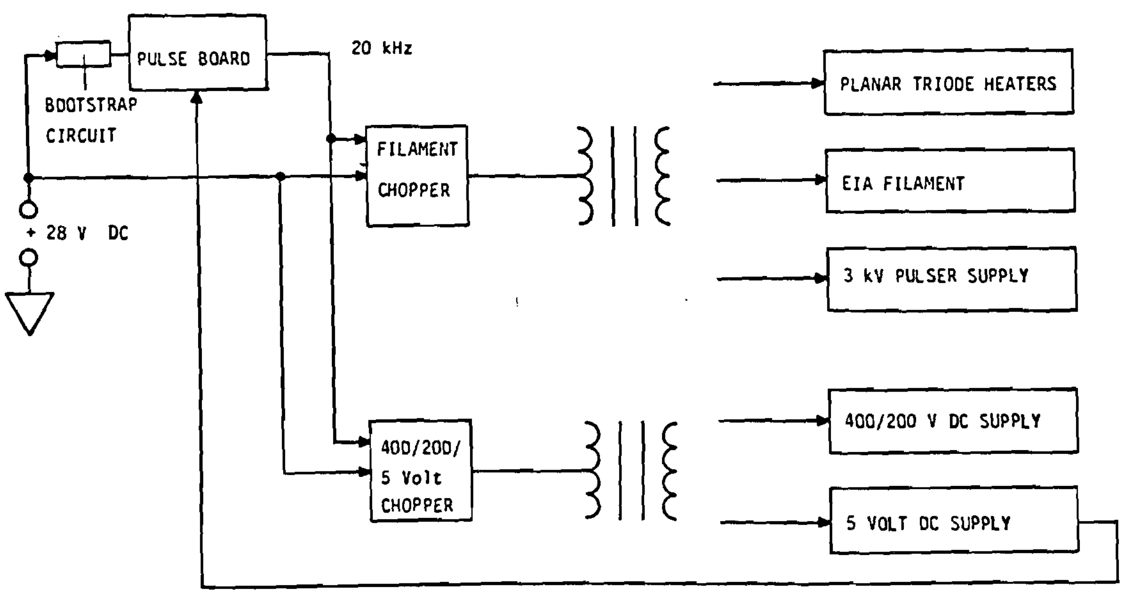


Figure 11. Power supply block diagram.

wave rectification. The 200 Vdc is obtained by a zener regulator in parallel with the 400 Vdc output. The 5 Vdc output is obtained from the output terminal of a MC7805 5V regulator. Since the 20 kHz chopper drive input requires 5 Vdc to operate, a bootstrap circuit is included to connect the 28 Vdc directly to the input of the MC7805 regulator during the initial turn-on time.

SECTION 4
PACKAGING AND OPERATION

4.1 DESCRIPTION

The pulser/power supply (which consists of the pulser, high voltage power supplies, low voltage power supplies, pulse generator, and control circuits) is packaged in a single rectangular unit designed with sufficient mechanical stability and ruggedness to support the EIA. Access to the pulser/power supply is through the top plate to which the EIA tube and grid pulser are attached. Below the top plate are the power supplies and pulse control circuitry required to provide the proper voltage potentials and control.

With the exception of a high voltage insulated wire which is wound around the U-core transformer, all components that operate at -22 kV are enclosed in a 3/8 inch thick plexiglass container box. This plexiglass container is screwed together with nylon hardware, and all of its surface-to-surface gaps are filled with room temperature vulcanizer (RTV) for high voltage insulation. Figure 12 is a photograph of the pulser/power supply unit with a VKB 2445T EIO tube attached.

4.2 TUBE MOUNTING

The top plate of the pulser must be removed to mount an EIA tube. The tube wires that connect to the three miniature pin jacks under the EIA mount should be cut as short as possible. Figure 13 shows a top view of the connectors for the EIA leads and indicates the proper electrode connections.

While lowering the tube into place, insert the pins at the end of the EIA leads into their proper plug-in (filament, grid, or cathode) on the plexiglass box, as indicated in Figure 13. Fasten the EIA onto the pulser top plate with the required hardware, and replace the top plate.

4.3 OPERATING PROCEDURE

The waveguide connections to the input and output of the EIA must be fastened properly. The input should have a source of 95 GHz RF with an

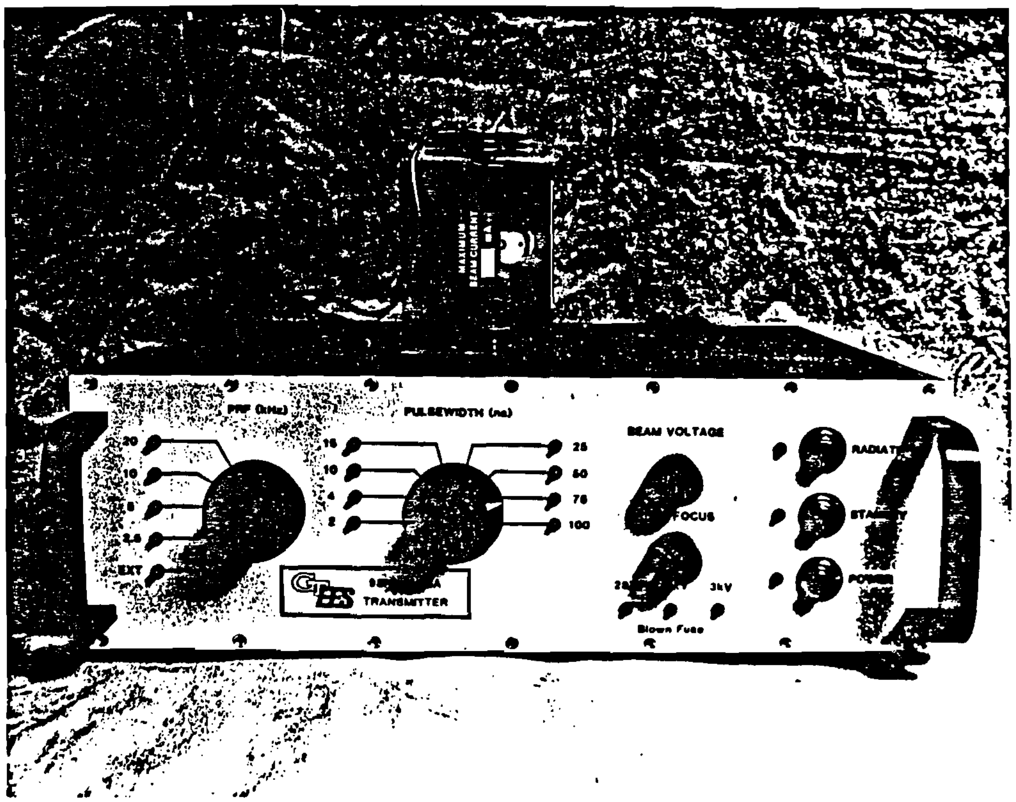


Figure 12. Pulser/power supply.

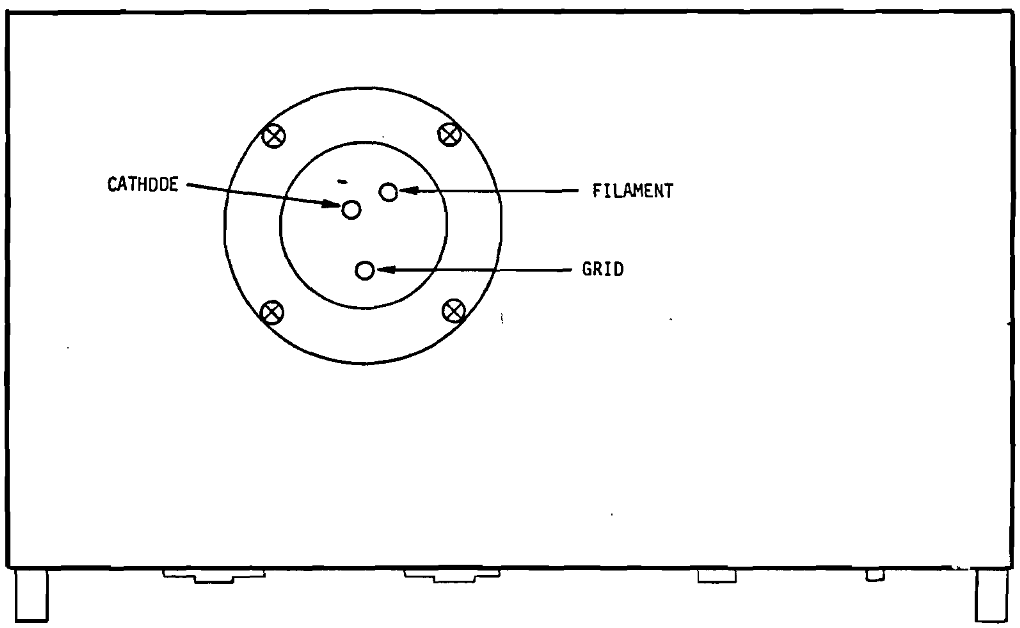


Figure 13. EIA connections (top view).

isolator for protection. The output of the EIA should have a proper load capable of handling 1 kW peak power.

The 28 Vdc input power should be connected to the screw terminals on the right side of the pulser. The 28 Vdc source must be capable of providing a current of at least 6 amperes during turn-on.

Turn-on Procedure:

a. Turn BEAM VOLTAGE and BEAM FOCUS fully counterclockwise.
b. Set PRF (kHz) as required. If an EXT sync is used, ensure that the PRF of the external signal generator is less than 20 kHz; otherwise there will be no output pulse.
c. Set the PULSEWIDTH (ns) as desired. If monitoring short pulses, a wideband oscilloscope is required.
d. Press the POWER switch. The yellow LED to its left should illuminate.
e. After approximately 2 minutes, the green LED should illuminate, indicating that all of the filaments have warmed up and the pulser is in STANDBY.

WARNING - BEWARE OF HIGH VOLTAGE

f. Monitor pulse collector current.
g. Press the RADIATE switch. The red LED light should illuminate. Increase focus voltage and beam voltage until the collector current pulse is 600 mA.
h. RF should be present at the output of the EIA unless the beam and/or focus voltage is misadjusted.
i. Adjust the focus voltage and increase the beam voltage until the RF is maximized. Small variations in focus and beam voltage can be made to vary the shape and size of the pulse.

SECTION 5
PERFORMANCE

The pulser was first tested on a VKB 2445T EIO provided by Varian, Canada. Injection priming was used to reduce the leading edge jitter and delay. A 95 GHz 15 mW Gunn source and high power Faraday rotational circulator were used to inject the signal into the EIO waveguide output. Figure 14 shows the detected RF power and collector current. Figure 15 shows a double exposure of the detected RF pulse with the smaller pulse attenuated 3 dB to show the 3 dB pulse width of 1.7 ns. The 1.6 ns 10% to 90% rise time and 0.9 ns fall time are shown in Figure 16. The long pulse performance is limited to approximately 100 ns due to droop caused by the inductive coupling to switch tube V_1. Figure 17 shows the detected RF pulse of the EIO with no priming, and Figure 18 shows the detected RF pulse with 10 mW priming. Note the reduction in leading edge delay and jitter that results from the injection priming.

A VKB 2449T1 EIA was available for only a few hours during which it could be used for a short pulse test. Figure 19 shows the detected RF pulse and collector current pulse. Figure 20 shows the double exposure of the detected RF pulse with one pulse attenuated 3 dB. The 3 dB RF pulse width is 1.4 ns. Figure 21 shows the rise time of 0.68 ns and Figure 22 shows the fall time of 0.80 ns. The short pulse 3 dB pulse width of 1.4 ns agrees with the predictions in Section 2.3.1. The EIA RF output pulse illustrated in Figure 19 is the initial pulse of a series of pulses generated by the periodic ringing of the 3 kV pulse V_{GK} with a period of approximately 15 ns.

Slight adjustments in both the pulser 3 kV supply and the -21 kV cathode supply affect the pulse shape, but the pulse shape remains stable over a 20% change in the +28 Vdc input voltage.

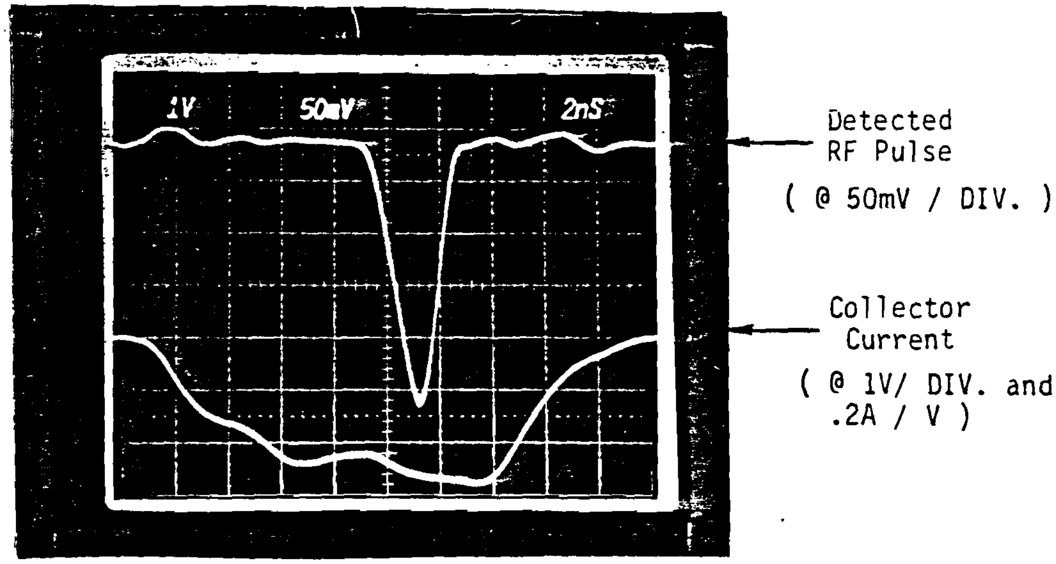


Figure 14. Primed EIO 1 kW detected RF and collector current pulses.

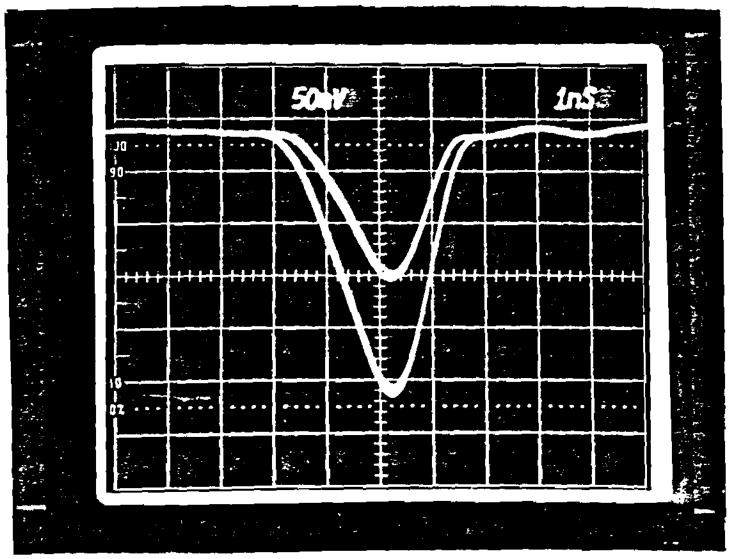


Figure 15. Double exposure of primed EIO pulse with 3 dB differential.

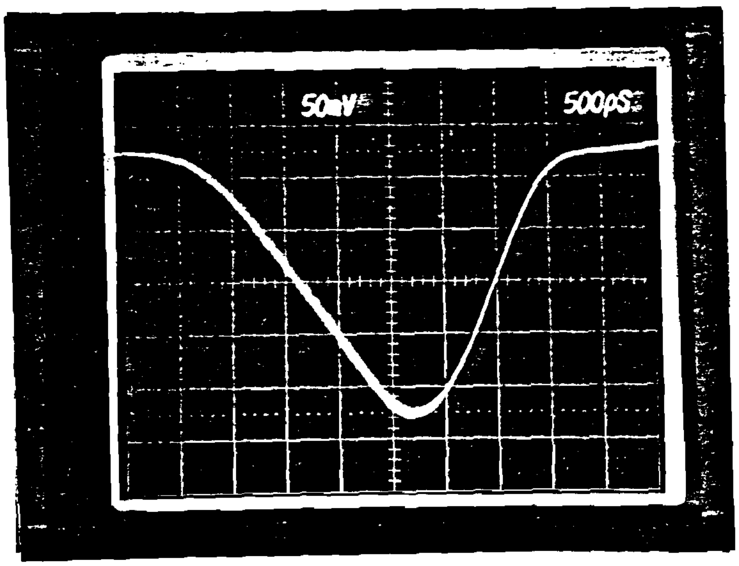


Figure 16. Primed EIO RF pulse rise and fall time.

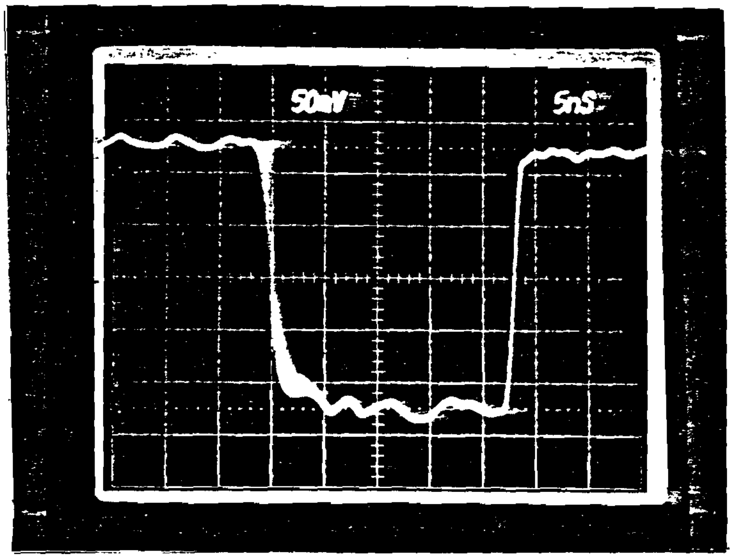


Figure 17. 1 kW EIO RF pulse without injection priming.

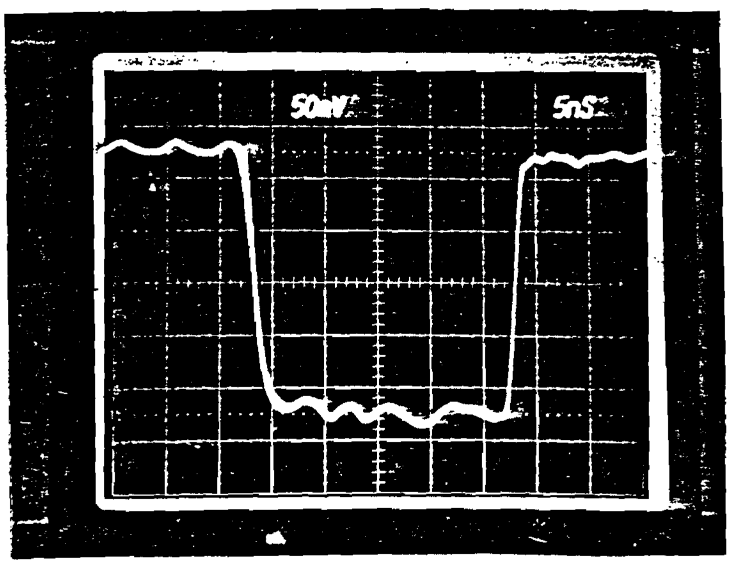


Figure 18. 1 kW EIO RF pulse with 10 mW injection priming.

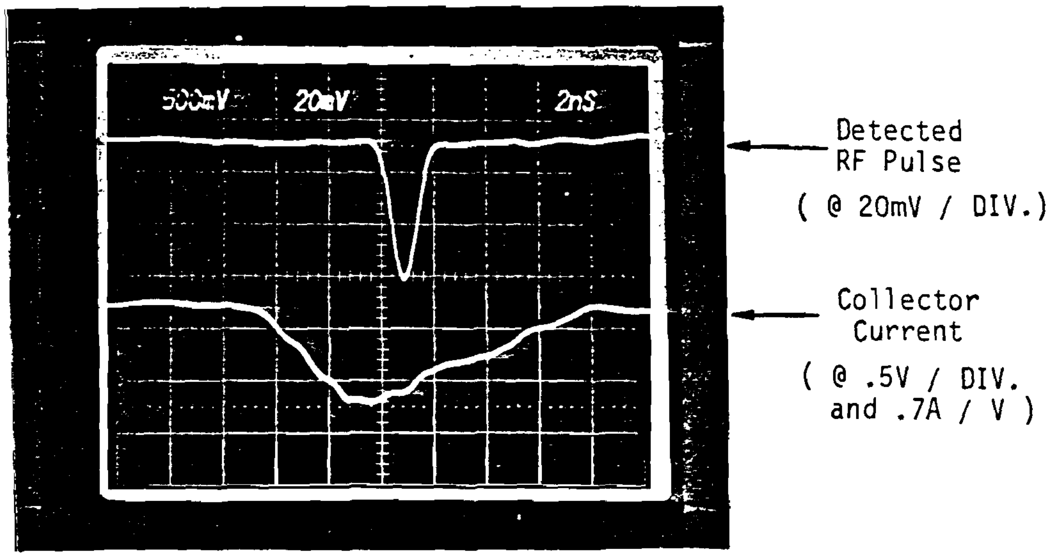


Figure 19. 2 kW EIA output RF and collector current pulse.

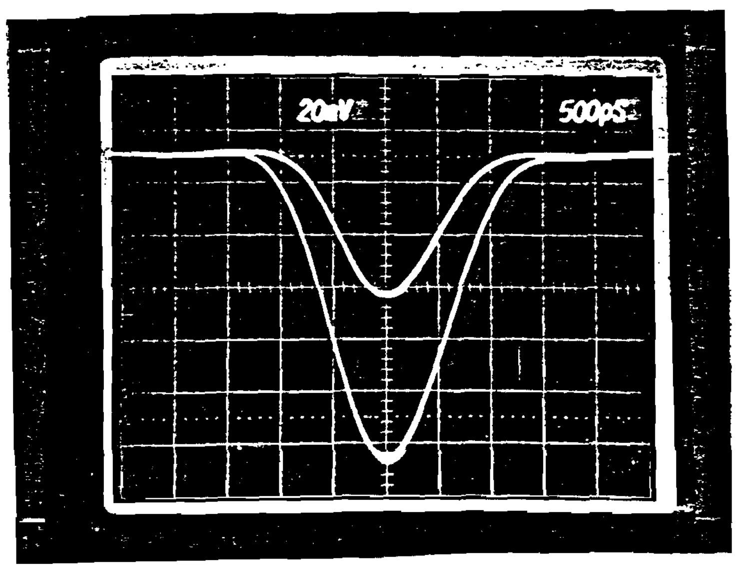


Figure 20. Double exposure of EIA output RF with 3 dB power differential.

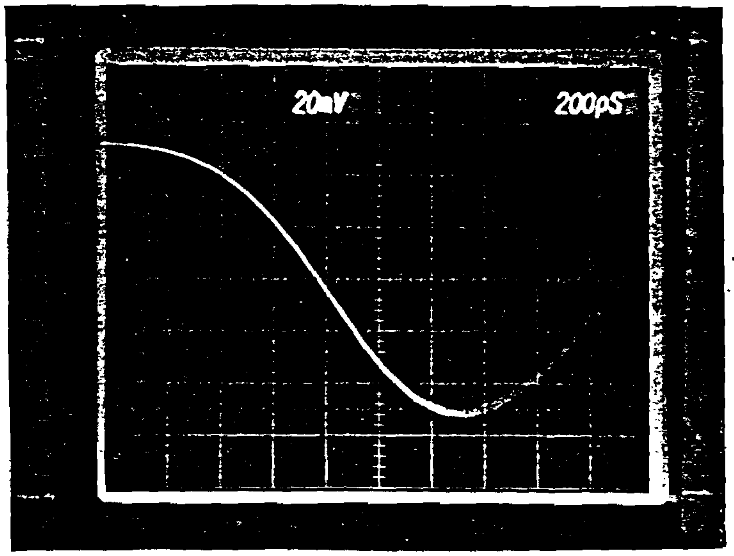


Figure 21. EIA output RF rise time.

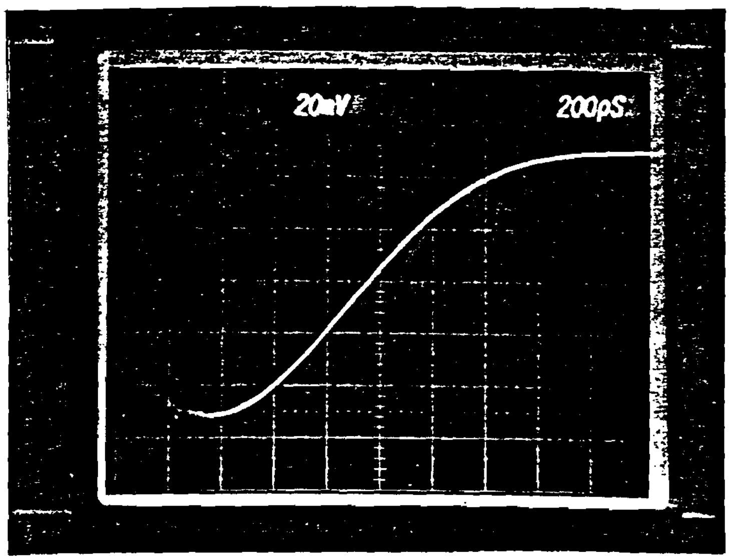


Figure 22. EIA output RF fall time.

SECTION 6
CONCLUSIONS AND RECOMMENDATIONS

6.1 PULSER CIRCUITS

The grid of the EIA or EIO must be effectively clamped to the cathode during the top of the pulse to achieve simultaneous long and short pulse performance. The pulser technique shown in Figure 23 is a floating deck pulser in which planar triode V_1 performs this clamping. In addition, since the pulser is at the EIA cathode potential, a physically smaller cathode grid circuit can be constructed to reduce the stray series inductance. One disadvantage is that all pulser power supplies and trigger circuits must be low capacitance and must withstand 21 kV. This can be accomplished by using high frequency dc-to-dc power converters and trigger pulse isolation transformers.

Since the RF pulse occurs only during the -100 V region of V_{GK}, a pedestal pulser technique such as the circuit shown in Figure 24 might be developed. A solid state pulser could provide a wide pulse of relatively poor shape which would get V_{GK} of the EIA to within 150 volts of the RF threshold. A short pulse could then be produced on top of this pedestal using avalanche transistors or FETs. A variety of circuits could be used to generate the pedestal. These might include the series high voltage FETs in a push-pull circuit as shown, a FET and step-up transformer with a resistively loaded secondary, or an SCR magnetic modulator. The RF duty cycle would be limited, since the EIA duty cycle is determined by the cathode current. Also, the pedestal would produce a more defocused beam which could be operated only at reduced duty cycle to limit the body current to the rated value. High voltage to the grid should be bypassed (as shown). The pulser should be enclosed in a Faraday shield, and the control pulse should be applied to the cathode. This will reduce the possibility of discharging the beam energy through the pulser in the event of a tube arc. Since the gridded EIA gun is constructed with the grid surrounding the cathode, the Faraday shield is effectively extended into the EIA tube.

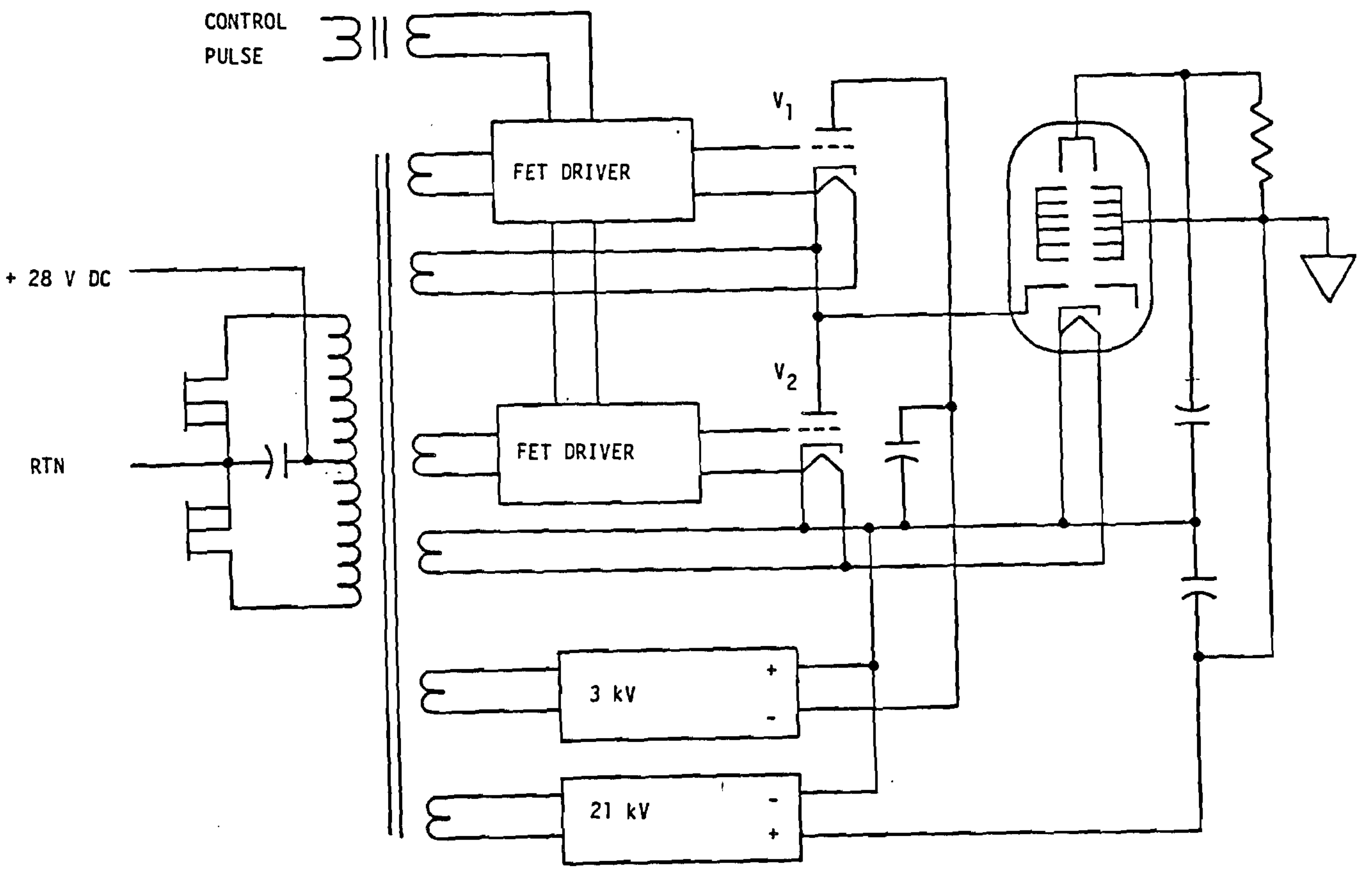


Figure 23. Floating deck pulser.

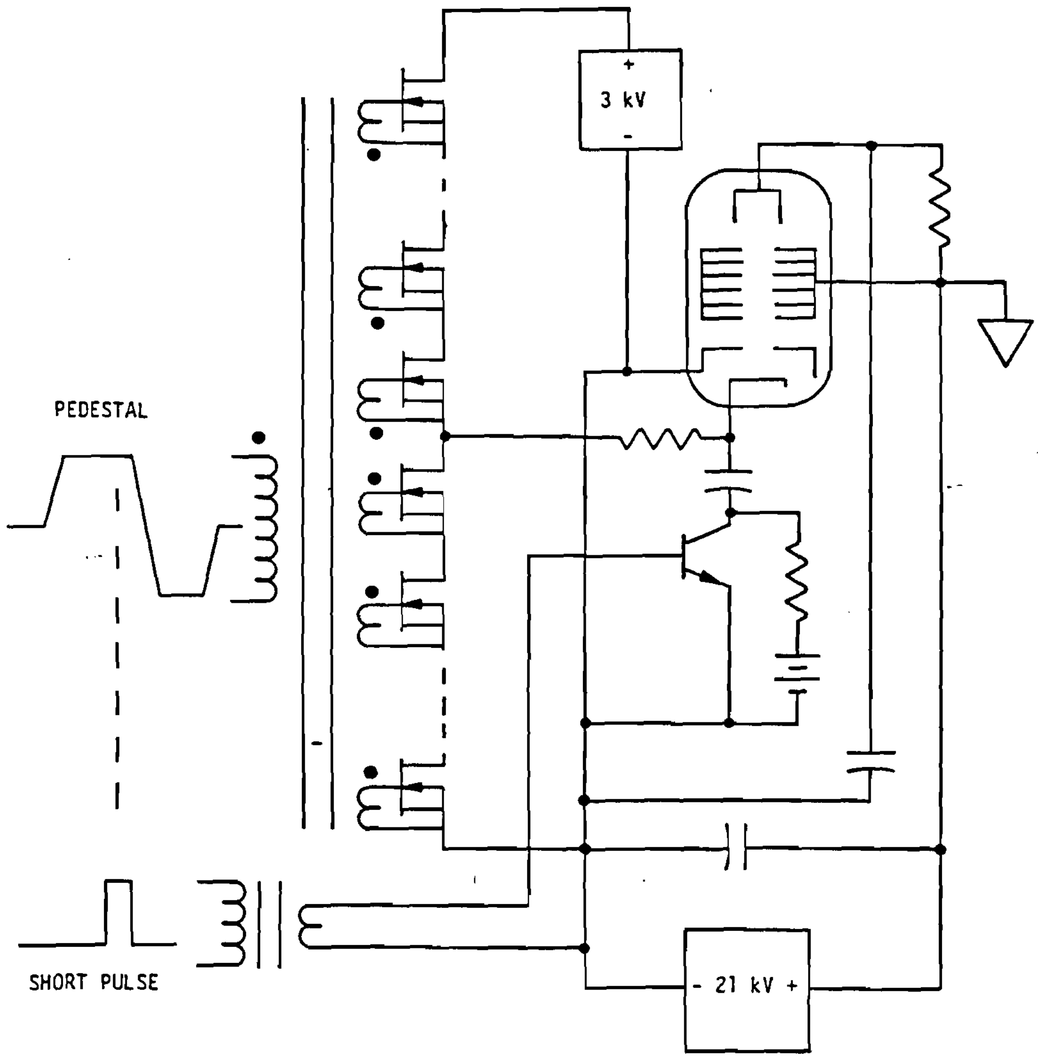


Figure 24. Solid state pulser.

6.2 CONSTRUCTION TECHNIQUES

The overall size of the pulse unit can be reduced by integrating the high voltage power supplies, the low voltage power supplies, isolation supplies, and control circuitry. In particular, most of the dc-to-dc converters could be consolidated into a single circuit. The physical size could also be reduced by using solid, high voltage encapsulation. A redesign of the present pulser could yield an estimated 60% to 70% volume reduction.

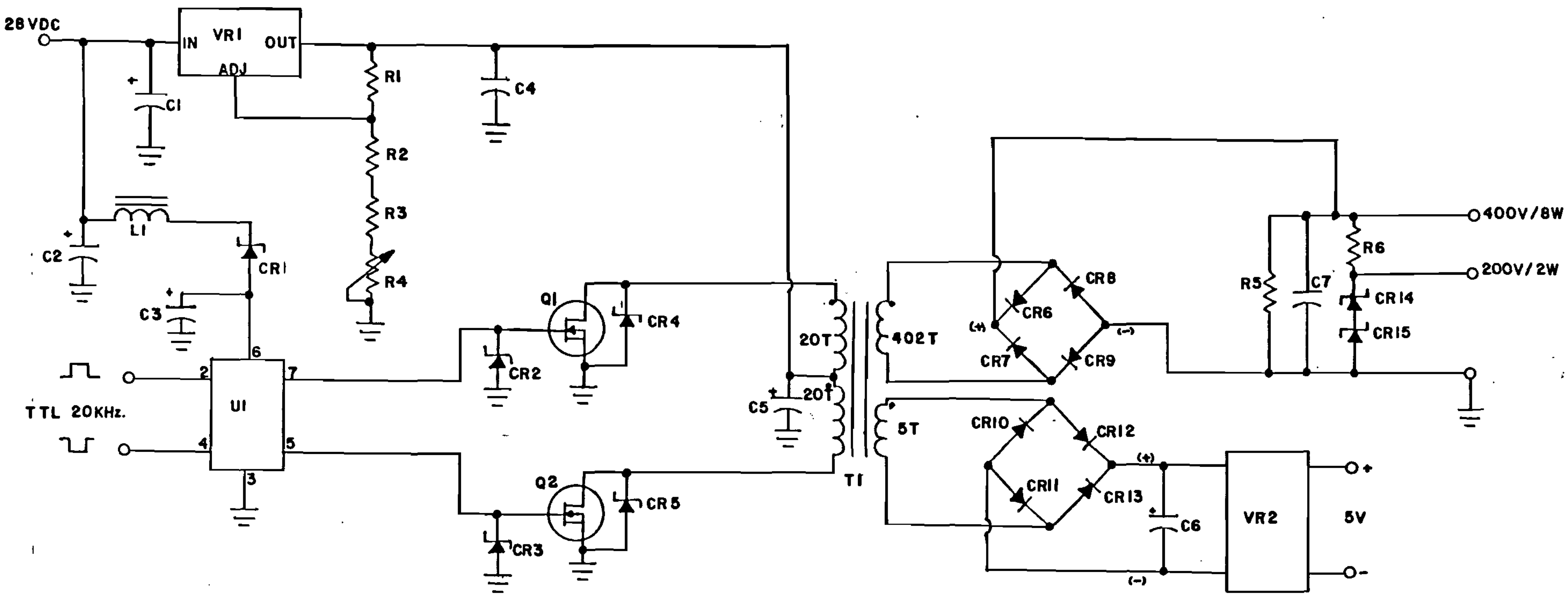
6.3 BONDED GRID

As the development of the focus electrode grid significantly changed the pulser design, development of the bonded grid EIO and EIA should greatly reduce the size and weight of the pulser circuit. The pulse voltage has been estimated to be only 500 volts. Such a pulser could use a power FET driven by avalanche transistors in a circuit such as the one used to drive the planar triodes.

6.4 RESULTS

This development program has resulted in a compact pulser/power supply capable of providing a minimum RF pulse width of 3 ns between -3 dB points when operated with the VKB 2449T1 EIA. The RF threshold as a function of grid to cathode voltage of an EIO was characterized due to the unavailability of an EIA. These measurements indicated that -20 dB cutoff point for the RF pulse occurs at a grid to cathode voltage of approximately -170 V. However, subsequent measurements on EIAs have indicated that the -20 dB cutoff point occurs at grid to cathode voltages as high as -1000 V.

APPENDIX A
SCHEMATIC DIAGRAMS



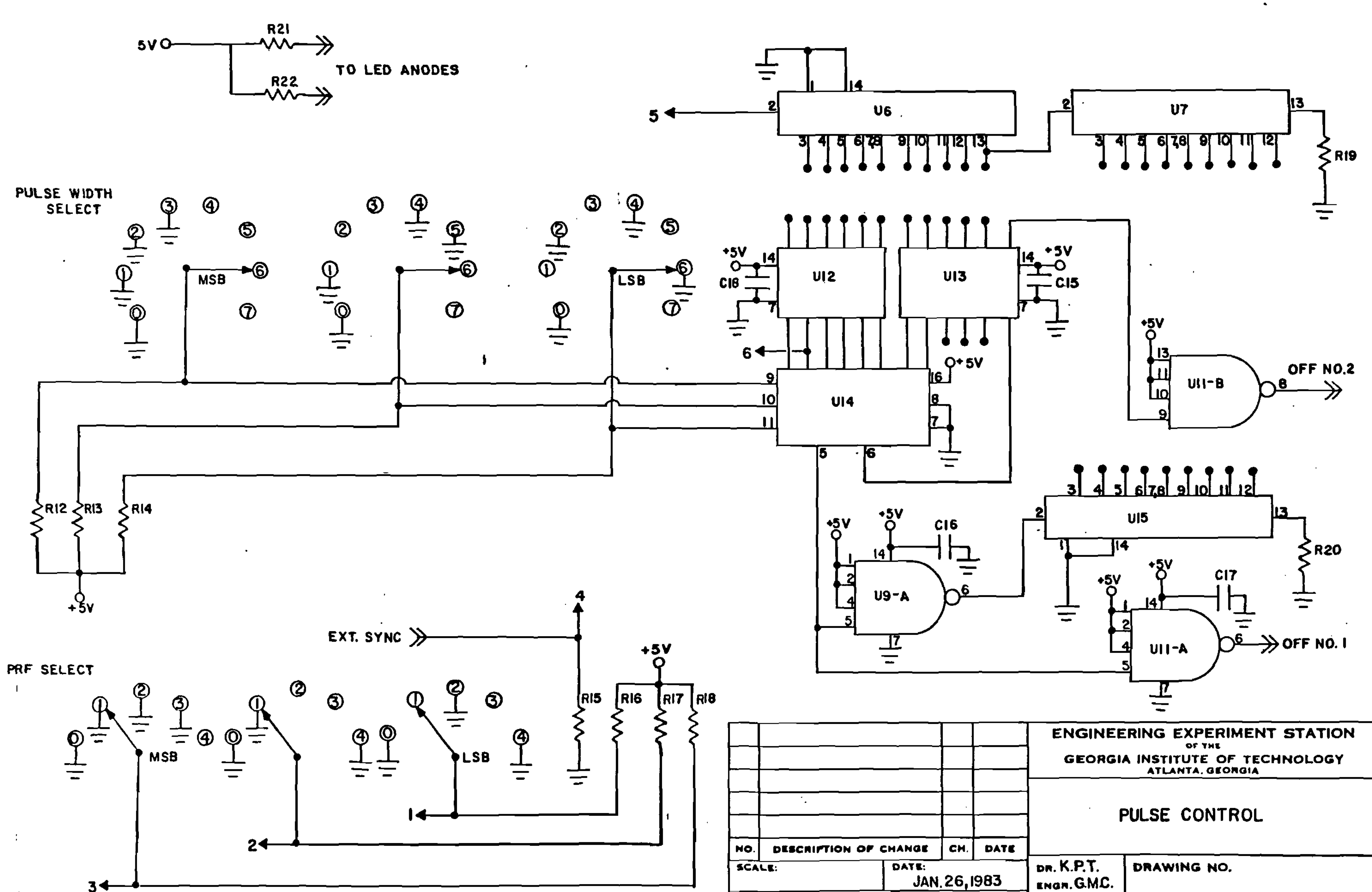
NO.	DESCRIPTION OF CHANGE	CH.	DATE

ENGINEERING EXPERIMENT STATION
OF THE
GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA

400/200/5V POWER SUPPLY

SCALE:
DATE: JAN. 17, 1983
CONTRACT NO.
PROJECT NO. A2968-000
DR. K.P.T.
ENGR. G.M.C.
CH.
APP.
DRAWING NO.

SEE SEPARATE PARTS LIST



SEE SEPARATE PARTS LIST

NO.	DESCRIPTION OF CHANGE	CH.	DATE

ENGINEERING EXPERIMENT STATION
OF THE
GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA

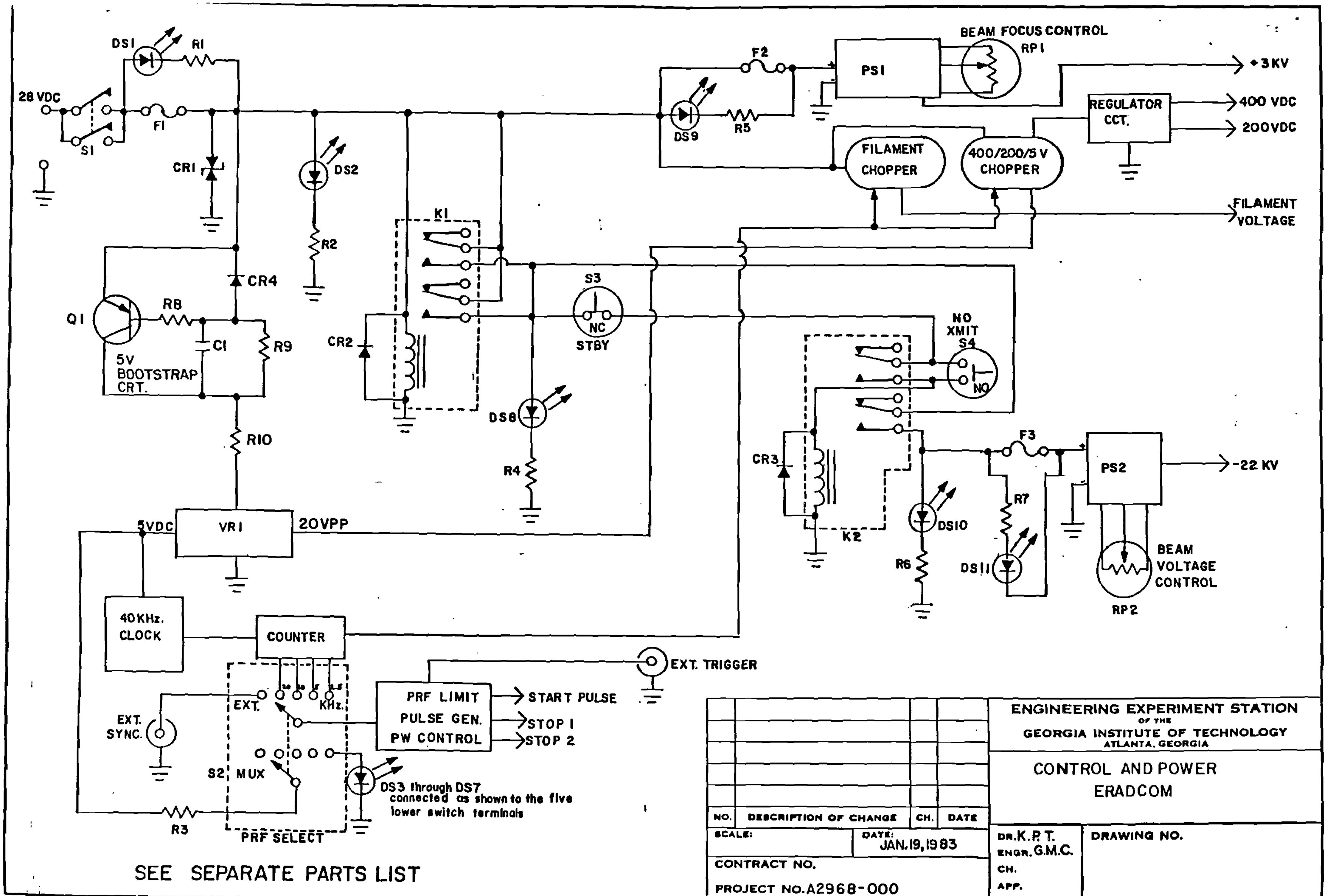
PULSE CONTROL

SCALE:
DATE: JAN. 26, 1983
CONTRACT NO.
PROJECT NO. A 2968-000

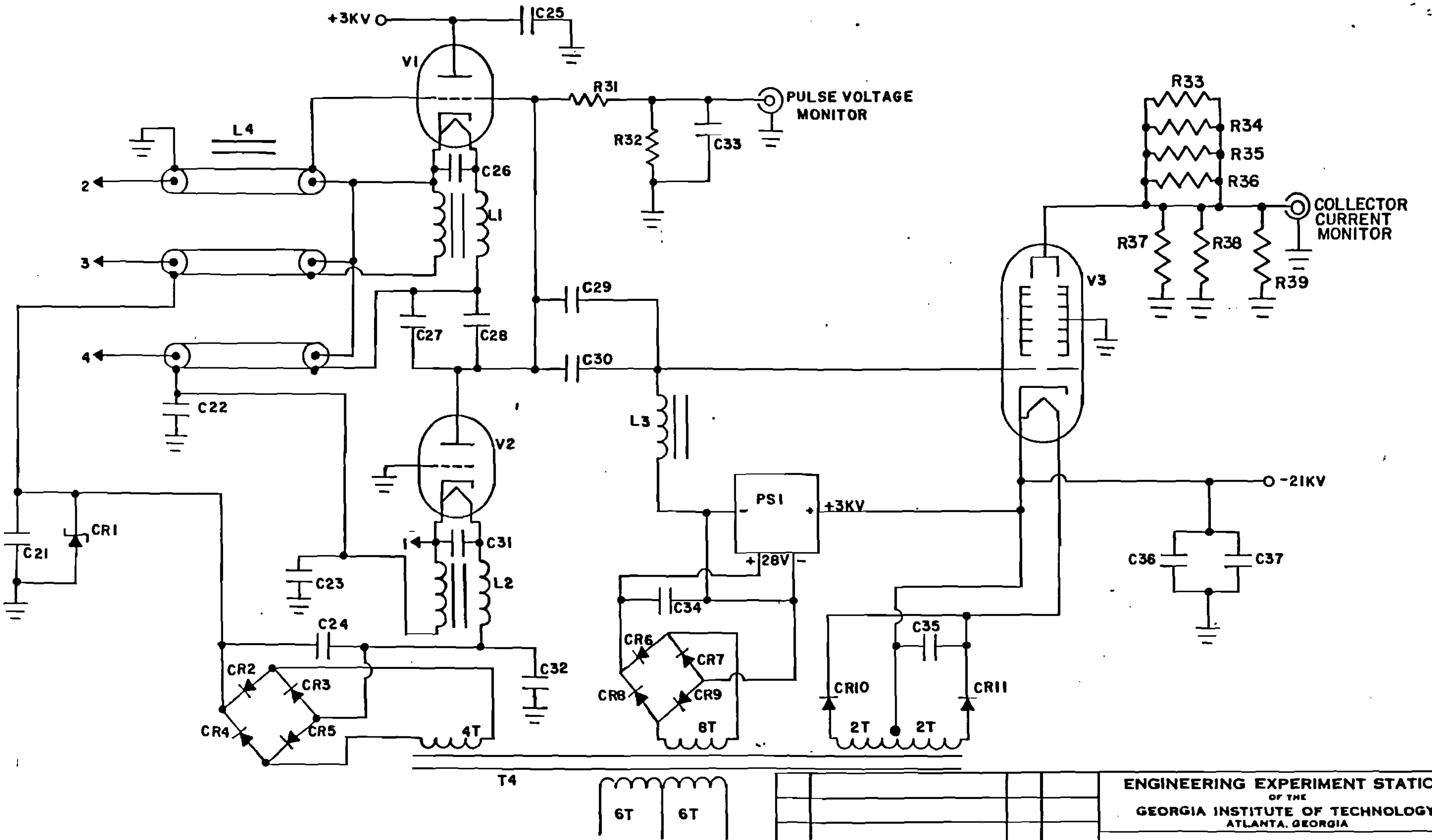
DR. K.P.T.
ENGR. G.M.C.
CH.
APP.

DRAWING NO.

SHEET 2 OF 2


28 VDC
S1
DS1
R1
F1
CR1
DS2
R2
CR4
Q1
R8
C1
R9
5V BOOTSTRAP CRT.
R10
VR1
5VDC
20VPP
40KHz. CLOCK
COUNTER
K1
CR2
S3
NC
STBY
DS8
R4
F2
PS1
DS9
R5
BEAM FOCUS CONTROL
RP1
+3KV
REGULATOR CCT.
400 VDC
200VDC
FILAMENT CHOPPER
400/200/5 V CHOPPER
FILAMENT VOLTAGE
NO XMIT
S4
NO
K2
CR3
F3
PS2
-22 KV
DS10
R6
R7
DS11
BEAM VOLTAGE CONTROL
RP2
EXT. TRIGGER
EXT. SYNC.
EXT.
KHz.
S2
MUX
PRF SELECT
R3
PRF LIMIT
PULSE GEN.
PW CONTROL
START PULSE
STOP 1
STOP 2
DS3 through DS7 connected as shown to the five lower switch terminals
SEE SEPARATE PARTS LIST
NO. DESCRIPTION OF CHANGE CH. DATE
ENGINEERING EXPERIMENT STATION OF THE GEORGIA INSTITUTE OF TECHNOLOGY ATLANTA, GEORGIA
CONTROL AND POWER
ERADCOM
SCALE:
DATE: JAN. 19, 1983
DR. K.P.T.
ENGR. G.M.C.
CH.
APP.
DRAWING NO.
CONTRACT NO.
PROJECT NO. A2968-000

AF 7114



NO.	DESCRIPTION OF CHANGE	CH.	DATE

ENGINEERING EXPERIMENT STATION
OF THE
GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA

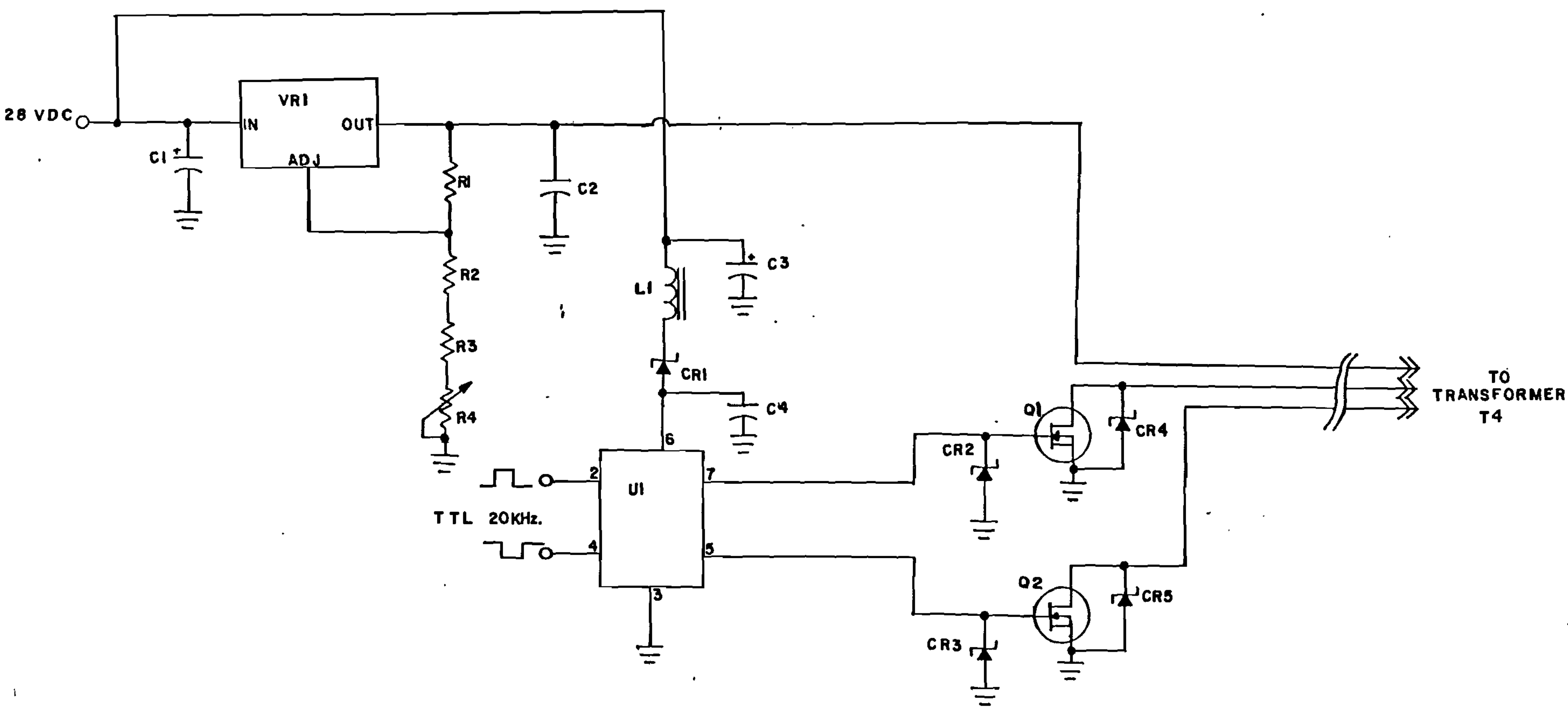
MODULATOR

SCALE:
DATE: FEB. 2, 1983
CONTRACT NO.
PROJECT NO. A2968-000

DR. K.P.T.
ENGR. G.M.C.
CH.
APP.

DRAWING NO.
SHEET 2 OF 2

SEE SEPARATE PARTS LIST



SEE SEPARATE PARTS LIST

NO.	DESCRIPTION OF CHANGE	CH.	DATE

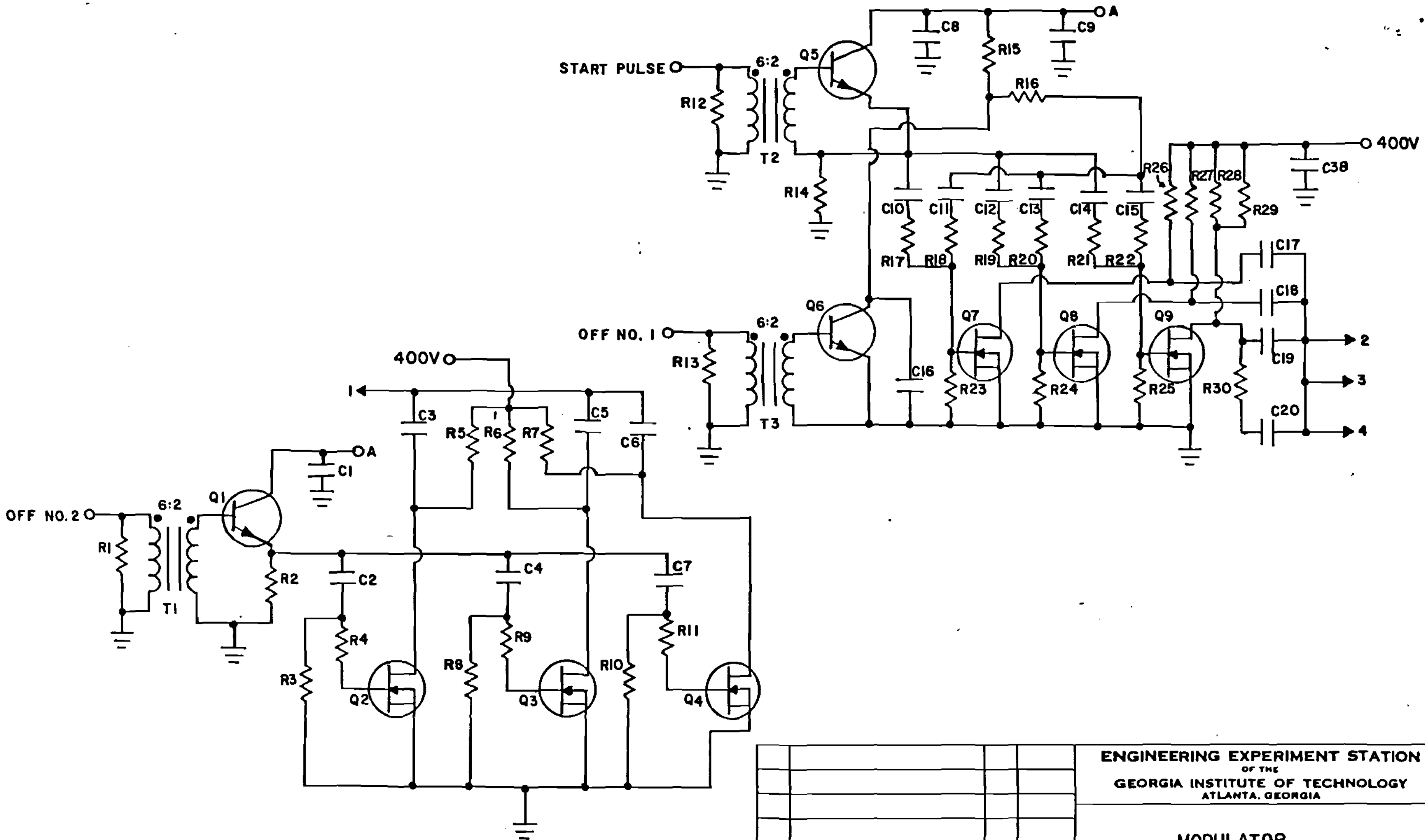
ENGINEERING EXPERIMENT STATION
OF THE
GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA

FILAMENT POWER SUPPLY

SCALE:
DATE: JAN.17, 1983
CONTRACT NO.
PROJECT NO. A2968-000

DR. K.P.T.
ENGR. G.M.C.
CH.
APP.
DRAWING NO.

K-E



SEE SEPARATE PARTS LIST

NO.	DESCRIPTION OF CHANGE	CH.	DATE

SCALE: | DATE: JAN. 31, 1983

CONTRACT NO.

PROJECT NO. A2968-000

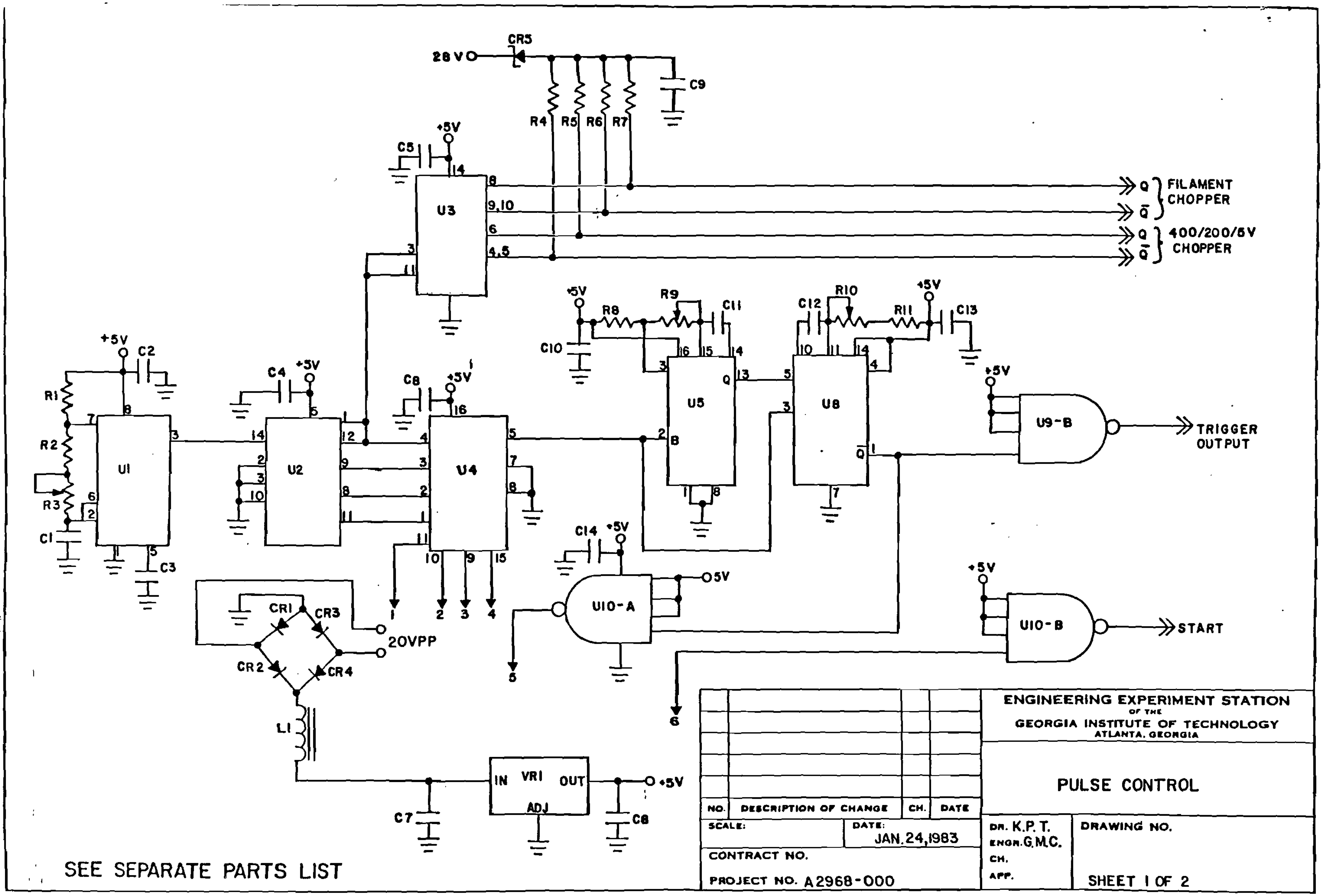
ENGINEERING EXPERIMENT STATION
OF THE
GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA

MODULATOR

DR. K.P.T.
ENGR. G.M.C.
CH.
APP.

DRAWING NO.

SHEET 1 OF 2


28 V
CR5
C9
R4
R5
R6
R7
+5V
C5
U3
Q
Q̄
FILAMENT CHOPPER
400/200/5V CHOPPER
C2
R1
R2
R3
C1
U1
C3
C4
U2
C8
U4
C10
R8
R9
C11
U5
C12
R10
R11
C13
U8
U9-B
TRIGGER OUTPUT
C14
U10-A
5V
U10-B
START
CR1
CR3
CR2
CR4
20VPP
L1
IN
VR1
OUT
ADJ
C7
C6
+5V
SEE SEPARATE PARTS LIST
NO.
DESCRIPTION OF CHANGE
CH.
DATE
ENGINEERING EXPERIMENT STATION
OF THE
GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA
PULSE CONTROL
SCALE:
DATE: JAN. 24, 1983
CONTRACT NO.
PROJECT NO. A2968-000
DR. K.P.T.
ENGR. G.M.C.
CH.
APP.
DRAWING NO.
SHEET 1 OF 2

APPENDIX B

PARTS LIST

Modulator Parts List

Ref.	Description	Ref.	Description
R1	47Ω	C17-C19	390 pF
R2	39 KΩ, 1/2 W	C20	.005 μF
R3	100 Ω	C21	.1 μF, 100 V
R4	10 Ω	C22	.1 μF
R5-R7	10 KΩ, 1 W	C23, C24	.1 μF, 100 V
R8	100Ω	C25	.01 μF, 5 kV
R9	10 Ω	C26-C28	.15 μF
R10	100Ω	C29, C30	460 pF, 30 kV
R11	10Ω	C31	.15 μF
R12, R13	47Ω	C32	.1 μF, 100 V
R14, R15	39 KΩ, 1/2 W	C33	25 pF
R16	27Ω	C34	10 μF, 35 V
R17-R22	10Ω	C35	4.7 μF, 35 V
R23-R25	1 KΩ	C36, C37	460 pF, 30 kV
R26, R27	10 KΩ, 1 W	C38	.047 μF, 400 V
R28, R29	4.7 kΩ, 2 W	CR1	1N 5375, 82 V Zener
R30	27Ω	CR2-CR5	MR 851
R31	10 KΩ, 15 W	CR6-CR9	MR 818
R32	100Ω	CR10, CR11	MR 851
R33	120Ω		
R34	120Ω		
R35	120Ω		
R36	120Ω		
R37	62Ω		
R38	62Ω		
R39	62Ω		

Modulator Parts List (continued)

Ref.	Description	Ref.	Description
C1	10 nF, 400 V	PS1	DRF405, 3 kV Power Supply
C2	47 pF		
C3	300 pF	Q1	RS 3500
C4	47 pF	Q2-Q4	IVN 6000
C5, C6	300 pF	Q5, Q6	RS 3500
C7	47 pF	Q7-Q9	IVN 6000
C8	10 nF, 400 V		
C9	.047 μF, 400 V		
C10-C16	50 pF		

L1	10 turns bifilar on two BBR7725 cores
L2	8 turns bifilar on BBR7725 core
L3	50 turns on BBR7727 core
L4	15 turns, trifilar wound 30 Ω coaxial cable on B64290J0046 toroid
T1-T3	PR6503, 6:2 turn ratio
T4	B67333 - Z001 - X043 U-core
V1, V2	8940 planar triode
V3	VKB2449 extended interaction amplifier

Pulse Control Parts List

Ref.	Description	Ref.	Description
R1	1 K Ω	C11	.1 μF
R2	470 Ω	C12	20 pF
R3	Variable, 1 K Ω	C13-C18	.1 μF
R4-R7	1 K Ω		
R8	680 Ω	L1	1 turn on ferrite bead
R9	Variable, 1 KΩ		
R10	Variable, 10 KΩ	CR1-CR4	MR 818
R11	1.5 K Ω	CR5	1N 4740, 10 V Zener
R12-R14	4.7 K Ω		
R15	47 Ω	VR1	MC 7805
R16-R18	4.7 K Ω		
R19, R20	100 Ω	U1	LM 555, 40 kHz oscillator
R21, R22	15 Ω	U2	7493
		U3	7406
C1	.01 μF	U4	74S151
C2	1 μF	U5	74123
C3, C4	.1 μF	U6	PE 9824, 5 ns delay line
C5	1 μF	U7	PE 9828, 10 ns delay line
C6	.1 μF	U8	74121
C7	10 μF	U9-U11	74S140
C8	.1 μF	U12, U13	8T93
C9	.1 μF, 50 V	U14	74S151
C10	1 μF	U15	PE 9824, 5 ns delay line

Filament Power Supply Parts List

Ref.	Description
R1,R2	100 Ω, 2 W
R3	150 Ω, 2 W
R4	100 Ω variable, 1 W
C1	1 μF, 50 V
C2	.1 μF, 35 V
C3	1 μF, 50 V
C4	.1 μF, 100 V
CR1	1N 4744, 15 V
CR2,CR3	1N 4742, 12 V
CR4,CR5	1N 4760, 68 V
Q1,Q2	IRF 130
U1	MMH0026 line driver
VR1	LM 223
L1	2 turns on bead
T1	B64290-A0040, bifilar wound

Control and Power Parts List

Ref.	Description
R1,R2	1.2 K Ω, 1 W
R3	150 Ω
R4,R5	1.2 KΩ , 1 W
R6	1 K Ω, 1 W
R7	820 Ω, 2 W
R8	3 K Ω
R9	1 M Ω
R10	10 Ω/1/2 W
RPI	10 K Ω, 10 turn potentiometer
RP2	10 K Ω, 10 turn potentiometer
K1	W67CDSOX-4, 4 min. TD relay
K2	W67RCSX Magnecraft relay
F1	10 A
F2,F3	1 A
DS1	Red
DS2-DS7	Yellow
DS8	Green
DS9-DS11	Red
PS1	3 kV, DRM 145 20 W HV power supply
PS2	-22 kV, ARA 196 20 W HV power supply (modified to DRM series)
C1	10 µf/35 V
CR1	V39MA2A
CR2,CR3	1N 4002
CR4	1N 4002
S1	DPDT 3A switch
S2	74151 mux control
S3	NC, pushbutton
S4	NO, pushbutton
VR1	MC 7805
Q1	T1P42

400/200/5 Vdc Power Supply Parts List

Ref.	Description
R1,R2	100 Ω, 2 W
R3	150 Ω, 2 W
R4	100 Ω variable, 1 W
R5	1 M Ω, 1 W
R6	18 K Ω, 1/2 W
C1	1 μF, 50 V
C2,C3	1 μF, 50 V
C4	.1 μF
C5	25 μF, 35 V
C6	10 μF, 25 V
C7	.15 μF, 400 V
CR1	1N 4743, 13 V
CR2, CR3	1N 4745, 16 V
CR4,CR5	1N 4760, 68 V
CR6-CR9	MR 818
CR10-CR13	MR 851
CR14	1N 5378, 100 V
CR15	1N 5375, 82 V
VR1	LM 223
VR2	LM 7805
U1	MMH 0026 line driver
Q1, Q2	IRF 130
L1	2 turns on bead
T1	F1151-1-06 bobbin core

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APPENDIX C
PRODUCT SPECIFICATION SHEETS

Raytheon	RS 3500
Intersil	IVN 6000
Advanced High Voltage Co.	ARA 196
Advanced High Voltage Co.	DRF 405
Advanced High Voltage Co.	DRM 145

RAYTHEON

Silicon Planex* Avalanche Transistor

RS3500

Description

The Raytheon NPN Silicon Planex* transistor type RS3500 is designed for high breakdown voltages, and fast avalanche switching speed, useful in applications requiring rise times under 1 nanosecond.

Absolute Maximum Ratings

Collector to Base Voltage V_{CBO}	200 Volts
Collector to Emitter Voltage V_{CEO}	50 Volts
Emitter to Base Voltage V_{EBO}	7 Volts
Total Device Dissipation	
@Case Temperature 25°C	4.0 Watts
@Case Temperature 100°C	2.0 Watts
@Free Air Temperature 25°C	0.8 Watts
Junction Temperature (Operating)	—65°C ÷200°C
Storage Temperature	—65°C ÷200°C

Electrical Characteristics (TA = 25°C unless otherwise noted)

	Sym.	Conditions	Min.	Typ.	Max.	Units
Collector to Emitter Breakdown Voltage	BVCES	Ic = 10μA	200		300	Volts
Emitter to Base Breakdown Voltage	BVEBO	Ic = 10μA	7.0			Volts
Collector to Base Leakage Current	ICBO	VCB = 100V			1.0	μA
Emitter to Base Leakage Current	IEBO	VEB = 5.0V			1.0	μA
Collector to Emitter Saturation Voltage	VCE(s)	10mA, 1mA			0.3	Volts
Base to Emitter Saturation Voltage	VBE(s)	10mA, 1mA			0.9	Volts
Collector to Emitter Breakdown Voltage	BVCEO	Ic = 10mA	50			Volts
Rise Time	tR	(Figure 1)		0.8		nS
Pulse Width	PW	(Figure 1)		3.0		nS
Pulse Amplitude	V pulse	(Figure 1)		190		Volts

*Planex—Raytheon's Designation For Planar Epitaxial

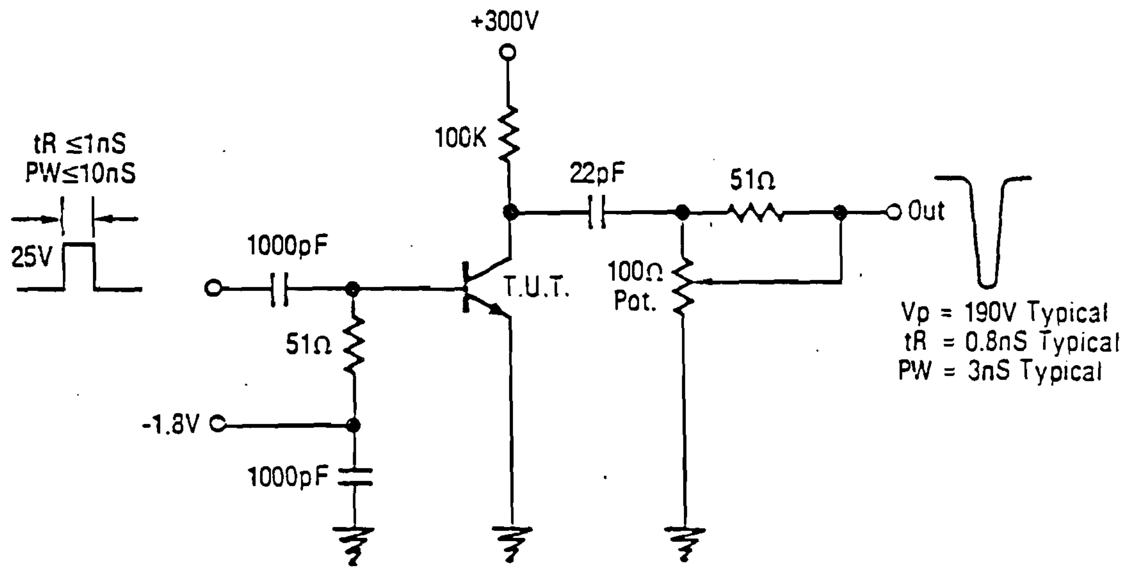
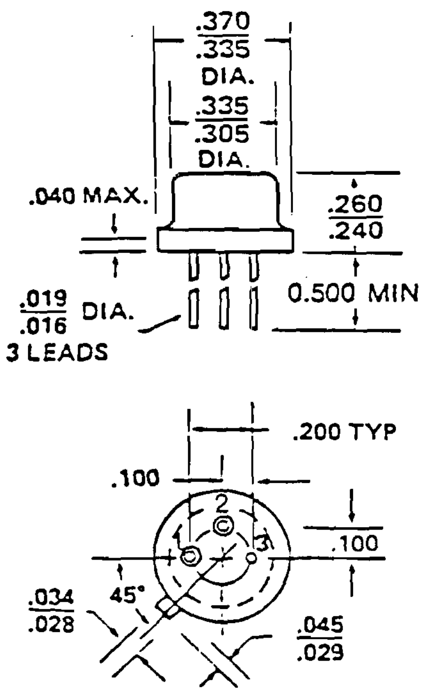


Figure 1. Avalanche Switching Circuit

Packaging Information

3-Lead TO-5 Package



Mechanical Data

Case:

JEDEC TO-5

Terminal Connections:

Lead 1 Emitter
Lead 2 Base
Lead 3 Collector (electrically connected to case)

RAYTHEON

INTERSIL

IVN6000 KN Series 450V n-Channel Enhancement-mode Vertical Power MOS FETs

FEATURES

- High speed, high current switching
- Inherent current sharing capability when paralleled
- Directly interfaces to CMOS logic
- Simple, straight-forward DC biasing
- Extended safe operating area
- Inherently temperature stable

APPLICATIONS

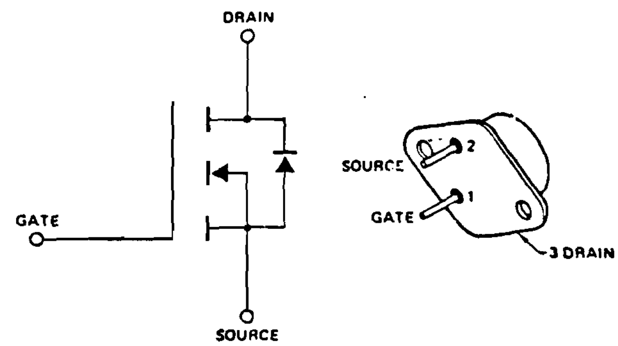
- Switching power supplies
- DC to DC inverters
- Motor controllers
- Power amplifiers
- RF amplifiers

ABSOLUTE MAXIMUM RATINGS
(T_A = 25° C unless otherwise noted)

Drain-source Voltage
IVN6000KNR 350V
IVN6000KNS 400V
IVN6000KNT 450V
Drain-gate Voltage
IVN6000KNR 350V
IVN6000KNS 400V
IVN6000KNT 450V
Continuous Drain Current 2.25A
Peak Drain Current (see note 1) 7.5A
Gate-source Voltage .... ±30V
Thermal Resistance, Junction to Case ... 3.5°C/W
Continuous Device Dissipation at (or below) 25°C Case Temperature 36W
Linear Derating Factor ....240mW/°C
Operating Junction Temperature Range .... −55 to +150°C
Storage Temperature Range .... −55 to +150°C
Lead Temperature (1/16 in. from case for 10 sec) .... +300°C
Reverse Diode Continuous Forward Current 3A
Reverse Diode Peak Forward Current 10A

Note Maximum pulse width 80μsec, maximum duty cycle 1.0%.

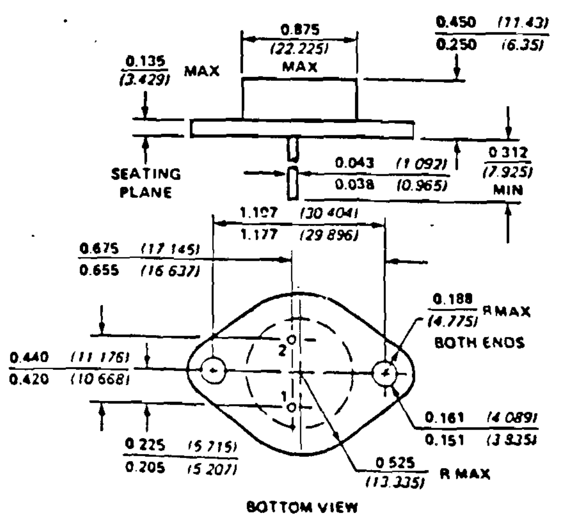
SCHEMATIC DIAGRAM



Body internally connected to source.
Drain common to case.

PACKAGE DIMENSIONS

PKG: JEDEC TO-3



Dimensions shown in inches and *(mm)*.

INTERSIL, INC., 10710 N. TANTAU AVE., CUPERTINO, CA 95014 (408) 996-5000 TWX: 910-338-0171

ELECTRICAL CHARACTERISTICS $T_A = 25°C$, unless otherwise specified

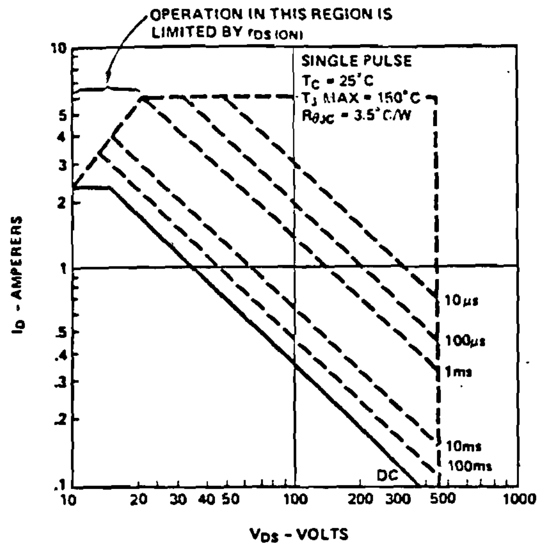
PARAMETER	SYMBOL	TEST CONDITIONS	LIMITS MIN.	TYP.	MAX.	UNIT
Drain-Source Breakdown Voltage IVN6000KNR	BV_{DS}	$V_{GS} = 0V$ $I_D = 100\mu A$	350			V
IVN6000KNS			400			V
IVN6000KNT			450			V
Gate-Threshold Voltage	$V_{GS(th)}$	$V_{DS} = V_{GS}$, $I_D = 10$ mA	2		5	V
Gate-Body Leakage Current	I_{GSS}	$V_{GS} = 30$ V		10	100	nA
Zero Gate Voltage Drain Current	I_{DSS}	V_{DS} = Maximum Rating, $V_{GS} = 0V$ $T_J = 125°C$		0.2	2	mA
ON Drain Current[1]	$I_{D(on)}$	$V_{DS} = 25V$, $V_{GS} = 15V$	4			A
Static-Drain Source ON Resistance[1]	$r_{DS(on)}$	$V_{GS} = 15V$, $I_D = 1A$		2.5	3.0	Ω
Forward Transconductance[1]	g_{fs}	$V_{DS} = 200V$, $I_D = 1.5A$	0.8	0.9		mho
Input Capacitance	C_{iss}	$V_{DS} = 100V$, f = 1.0 MHz, $V_{GS} = 0V$		220	300	pF
Output Capacitance	C_{oss}	$V_{DS} = 100V$, f = 1.0 MHz, $V_{GS} = 0V$		22	30	pF
Reverse Transfer Capacitance	C_{rss}	$V_{DS} = 100V$, f = 1.0 MHz, $V_{GS} = 0V$		6	10	pF
Rise Time	t_r	$V_{DS} = 200V$, $I_D = 1.0A$, $V_{GS} = 15V$, $R_{gen} = 6\Omega$			10	ns
Fall Time	t_f	$V_{DS} = 200V$, $I_D = 1.0A$, $V_{GS} = 15V$, $R_{gen} = 6\Omega$			10	ns

Note: 1. Pulse Test: 80μs, 1% duty cycle.

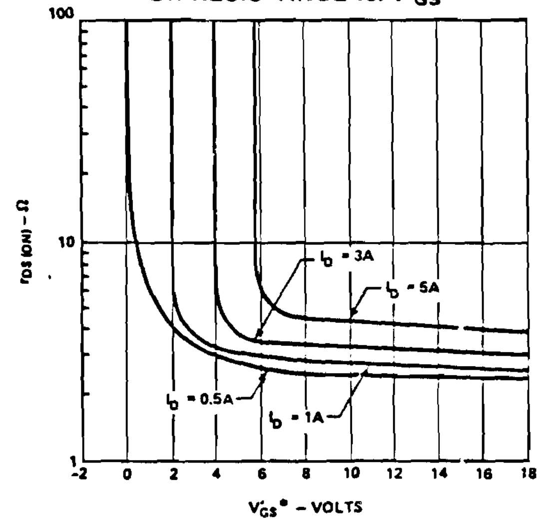
REVERSE DIODE CHARACTERISTICS

PARAMETER	SYMBOL	TEST CONDITIONS	LIMITS MIN.	TYP.	MAX.	UNIT
Forward Voltage Drop	V_f	Peak Forward Current = 2A		0.95	1.1	V
Reverse Recovery Time	t_{rr}	$I_{fwd(pk)} = I_{rev(pk)}$ Recovery to 50%	100			ns
Recovered Charge	Q_{rr}	$T_J = 150°C$, $I_{fwd(pk)} = 2A$	0.2			nC

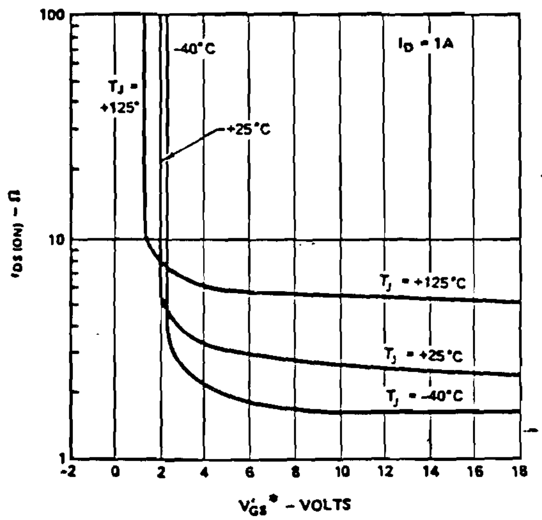
SAFE OPERATING AREA



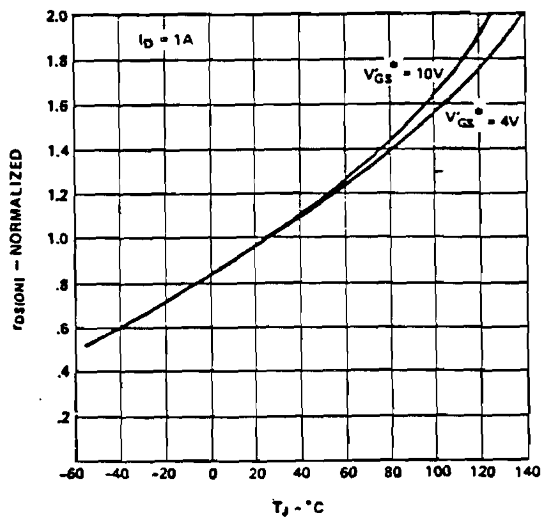
ON RESISTANCE vs. V'_{GS}*



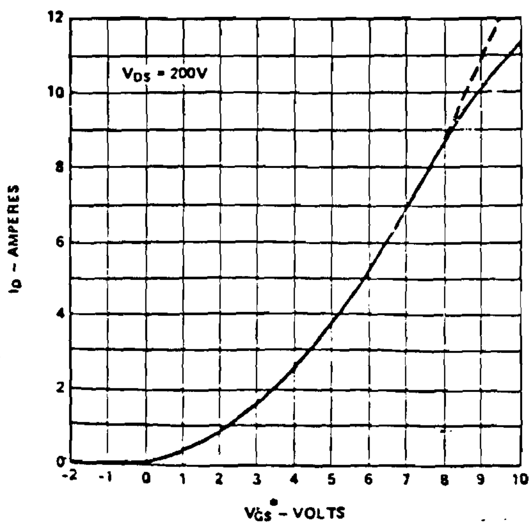
ON RESISTANCE vs. V'_{GS}*



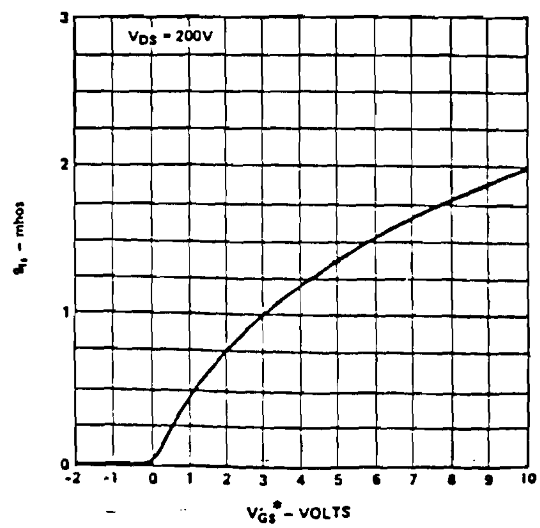
ON RESISTANCE vs. JUNCTION TEMPERATURE



TRANSFER CHARACTERISTICS

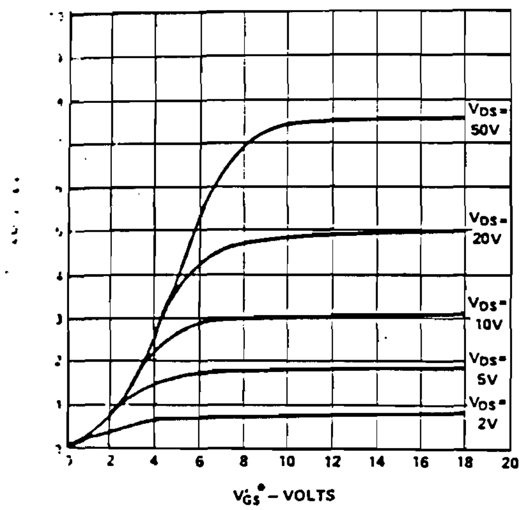


TRANSCONDUCTANCE CHARACTERISTICS

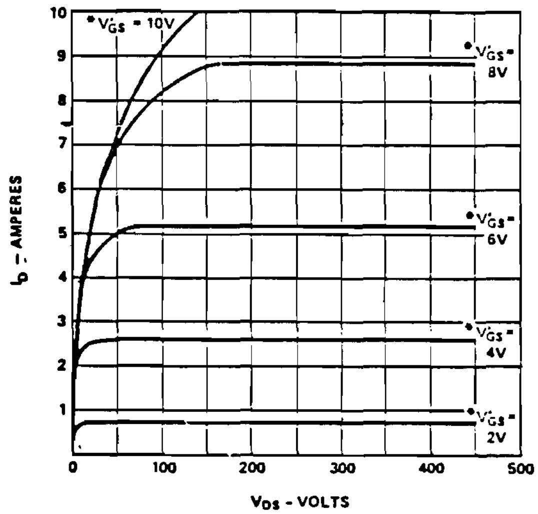


*$V'_{GS} = V_{GS} - V_{GS(th)}$

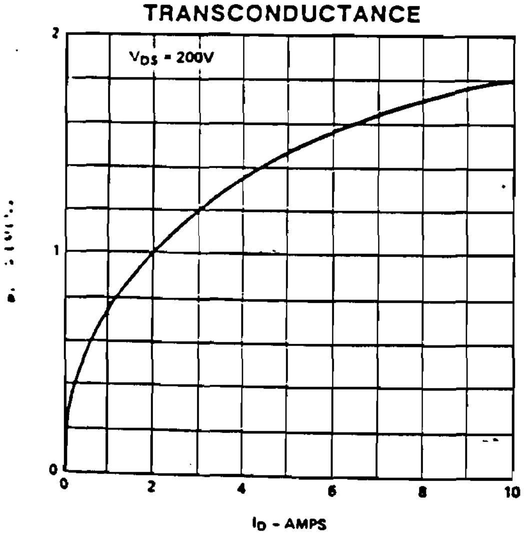
LARGE SIGNAL TRANSFER CHARACTERISTICS



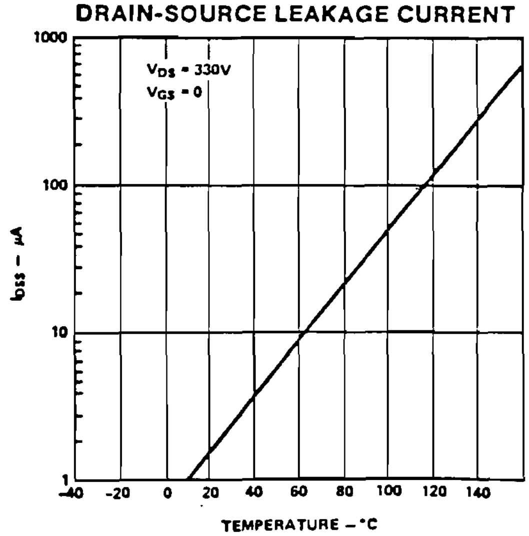
OUTPUT CHARACTERISTICS



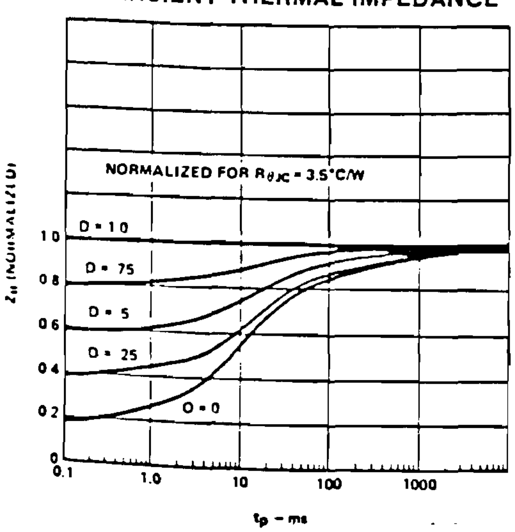
TRANSCONDUCTANCE



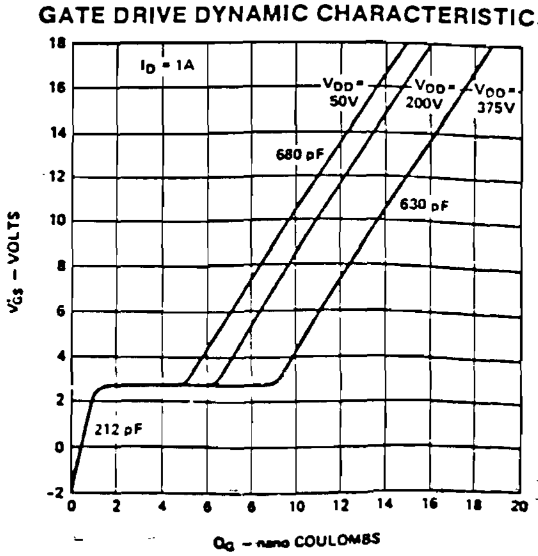
DRAIN-SOURCE LEAKAGE CURRENT



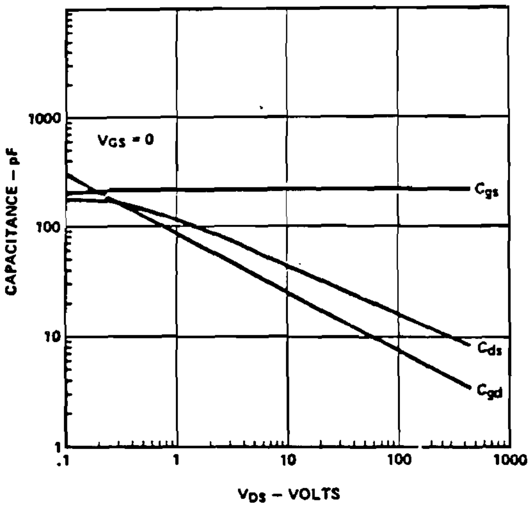
TRANSIENT THERMAL IMPEDANCE



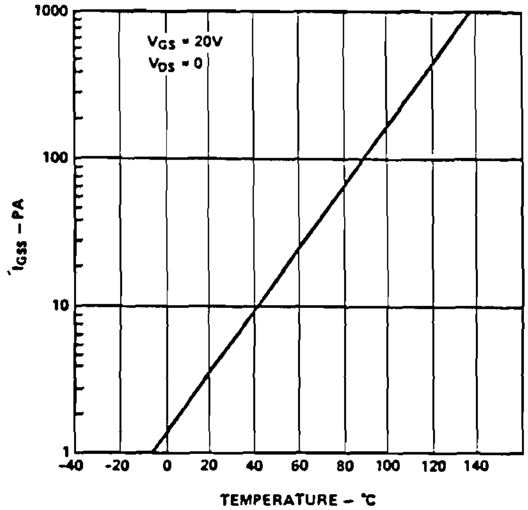
GATE DRIVE DYNAMIC CHARACTERISTICS



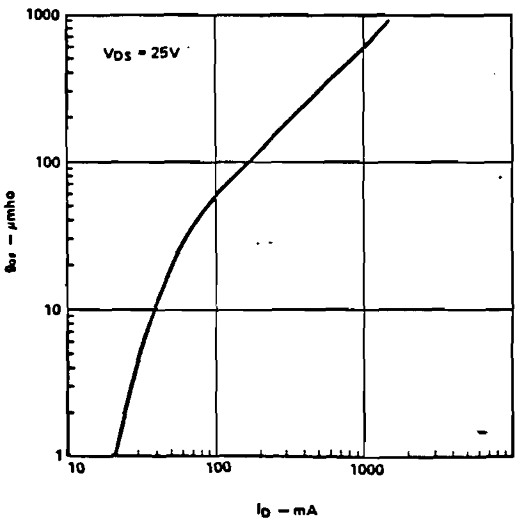
CAPACITANCE vs. DRAIN-SOURCE VOLTAGE



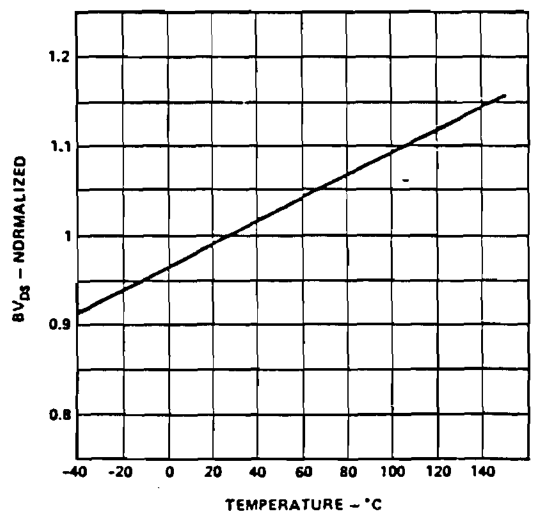
GATE LEAKAGE CURRENT



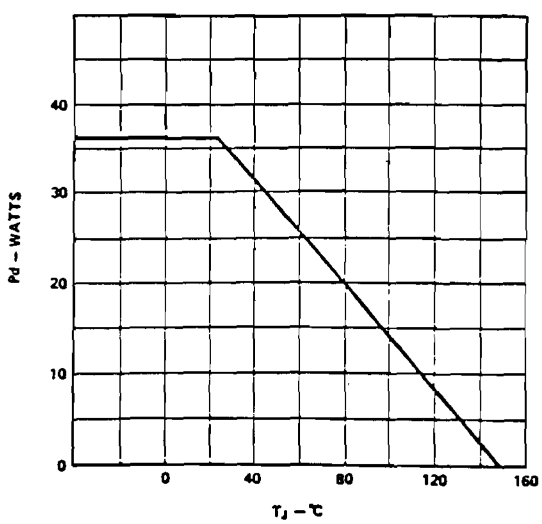
OUTPUT CONDUCTANCE



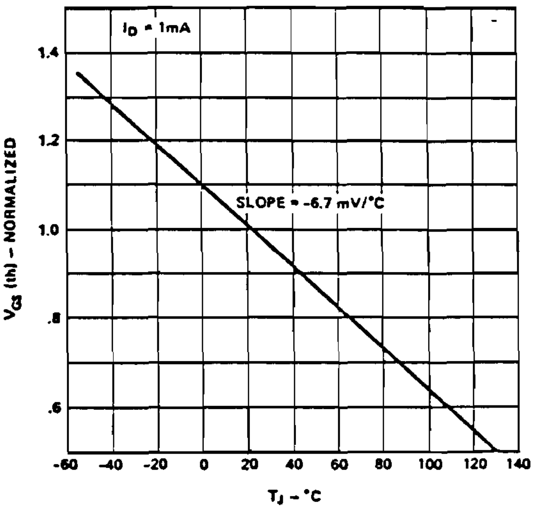
BREAKDOWN VOLTAGE VARIATION WITH TEMPERATURE



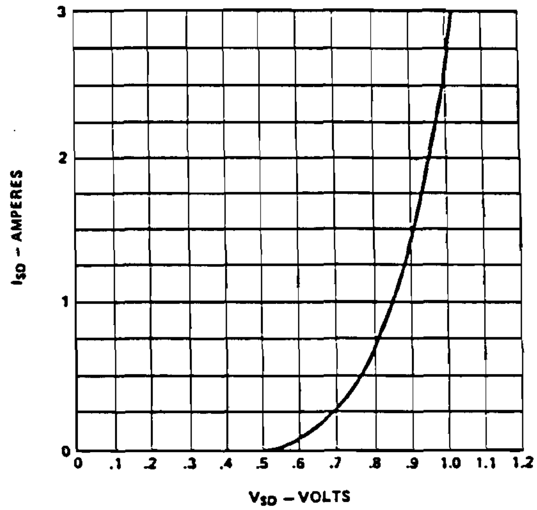
POWER DISSIPATION vs. TEMPERATURE DERATING



THRESHOLD VOLTAGE



DIODE FORWARD VOLTAGE CHARACTERISTICS



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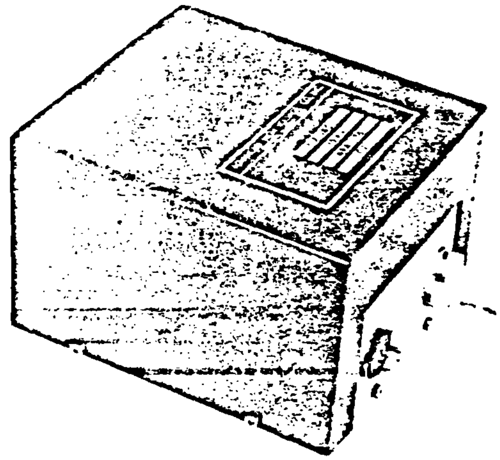
ADVANCED HIGH VOLTAGE CO., INC.
14532 ARMINTA AVE. • VAN NUYS, CALIF. 91402 • PHONE: (213) 997-7222

ARA Series
Line operated, regulated,
high voltage power supply.
4 to 18 KV out @ 16 watts.



APPLICATIONS

CRT displays, image converters & similar photo-tube applications. General high voltage uses where close regulation, low ripple and small size are important.

FEATURES

High frequency inverter type power supply. Features line and load regulation. Low ripple. Adjustable output voltage, min. ±500 volts. Recovers automatically from overload and short. Floating high voltage return (within 500 volts of case). Low energy storage in filter components. Conservatively rated. Compact package. Convenient mounting, studs or threaded holes. Easy-disconnect input and output connectors. Fully repairable low voltage section. Encapsulated high voltage section.

SPECIFICATIONS

Input: 117 VAC, 60 Hz.
Output: 4-18 KV @ 16 watts.
Regulation — Line: < 0.1%. Load: < 0.1%. Combined L/L: < 0.1%.
Ripple: Less than .1% rms.
Operating temperature: −20°C to +65°C. Weight: 2 lbs.
Size: 4.66 x 2.90 x 3.98 inches (plus connectors).

Model #	E_{out} nom.	I_{out} max.
ARA 106	3 KV	5 mA
ARA 116	4 KV	4 mA
ARA 126	5 KV	3 mA
ARA 136	6 KV	2.5 mA
ARA 146	8 KV	2 mA

Model #	E_{out} nom.	I_{out} max.
ARA 156	10 KV	1.5 mA
ARA 166	12 KV	1.2 mA
ARA 176	15 KV	1.0 mA
ARA 186	18 KV	.8 mA
ARA 196	22 KV	.6 mA

OPTIONS

Negative output polarity. Voltages not listed above. Different HV output connectors or HV cable. Delayed turn-on. Remote (low power) turn-on and shut-off. Remote programming, E or R. 50 Hz & 400 Hz line operation. Wider adjustment range. Output power to 40 watts.

REV 3/73

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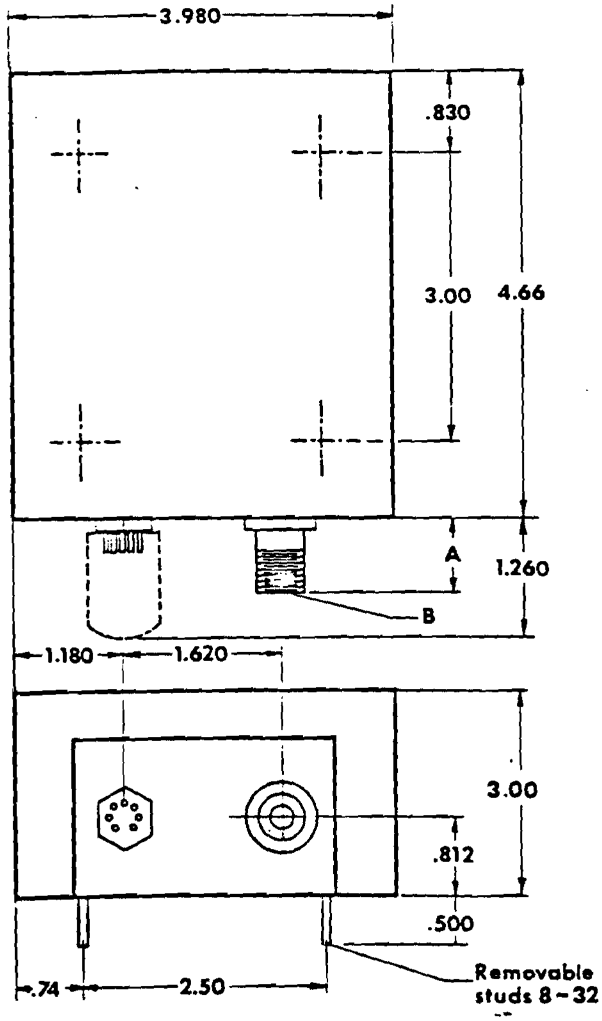

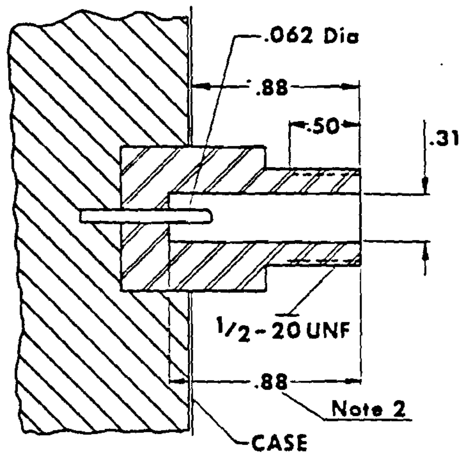

NOTES

1. Voltage adjustment is through top of unit.
2. 1.00 inch for units with 16 KV output and higher.
3. Mounting holes are on center-line.

TOLERANCES
Mounting Centers: ±.020
Others: ±.050

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ADVANCED HIGH VOLTAGE CO., INC.

14532 ARMINTA AVE. • VAN NUYS, CALIF. 91402 • PHONE: (213) 997-7222

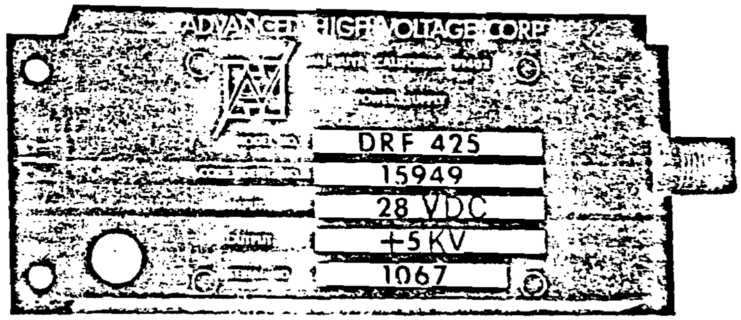
DRF Series
Miniature High Voltage
DC to DC converter
3 Watts output to 5.5 KV

APPLICATIONS

Photomultipliers, image intensifiers and similar photo tube applications where small size, close regulation are important.

FEATURES

Small size, low weight
Tight line and load regulation
Fully shielded
RFI decoupled
Factory serviceable
Encapsulated HV section



SPECIFICATIONS

Input: 28 VDC ±3V, 300 mA F.L.
Output for series: 180 V to 5500 V at 3 watts
Regulation. L/L: 0.02% RIPPLE: 0.02% P-P (wideband)
Operating temperature: −20 to +65°C (case temp. no derating)
Temperature Coefficient: 150 ppm (3, 4, & 5 KV), 100 ppm (2.5 KV & below).
Size: 1.5 x 3.0 x .6 (see outline).
Weight: 5 oz. max.

Model Number	E_{out}	I_{out}	Model Number	E_{out}	I_{out}
DRF 325	200 V	15 mA	DRF 375	1.5 KV	2 mA
DRF 335	400 V	7.5 mA	DRF 385	2 KV	1.5 mA
DRF 345	600 V	5 mA	DRF 395	2.5 KV	1.2 mA
DRF 355	800 V	3.7 mA	DRF 405	3 KV	1 mA
DRF 365	1.1 KV	3 mA	~~DRF 415~~	~~4 KV~~	0.8 mA
			~~DRF 425~~	~~5 KV~~	0.6 mA

OPTIONS

Negative output (—01), remote program, (—05), other input voltage (—33), wide output adjustment range (—04 other output voltages not listed here (—29), Tc of 50 ppm (—27), true hermetic seal with remote program (—42

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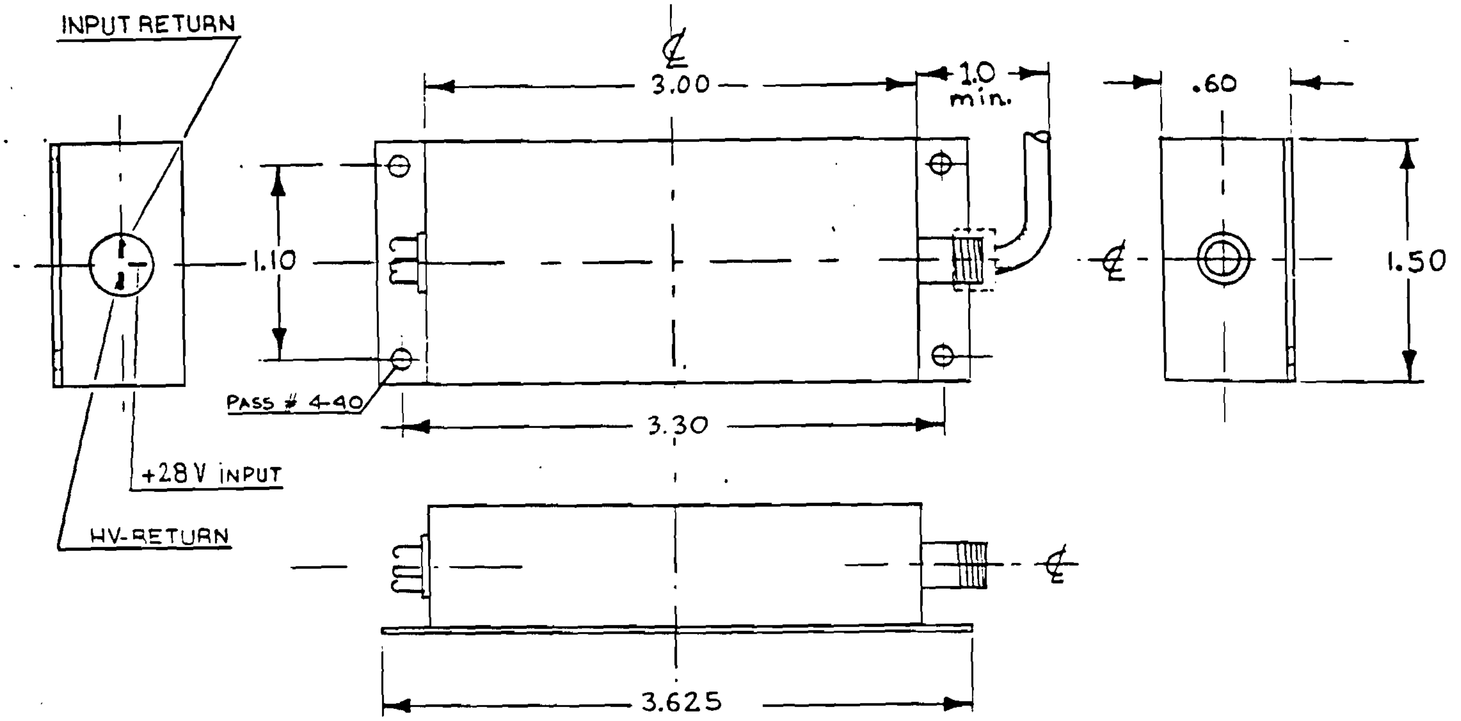

Units with 1 KV or less
output use feed-thru terminal
instead of HV connector.

HV Connector Part No.:
AMP 830178-1
REYNOLDS 167-9158

REPRESENTED BY:

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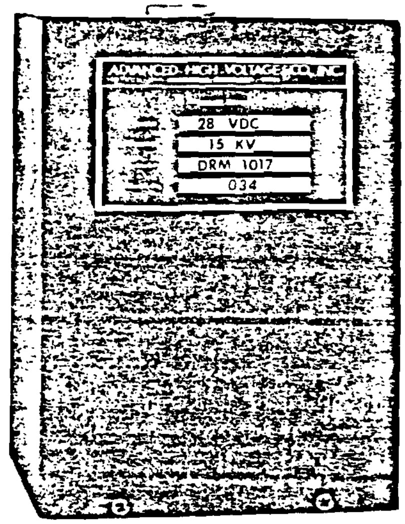
14[illegible]2 ARMINTA AVE. • VAN NUYS, CALIF. 91402 • PHONE: (213) 997-7222

DRM SERIES
DC operated HV Module.
800V to 22KV @ 15 watts. 28VDC input. Load and line regulated.



APPLICATIONS

CRT displays, image converters & similar photo-tube applications. General high voltage uses where close regulation, low ripple and small size are important.

FEATURES

Module type high voltage supply.
All solid state silicon.
Features line and load regulation.
Low ripple.
Short-circuit proof, output will recover upon removal of short.
Floating HV return. May be floated up to 500V from case or input.
Magnetically shielded.
Serviceable low voltage section.
Encapsulated high voltage section.

SPECIFICATIONS

Input: 28 VDC nominal.
Output: 800 V to 22 KV Adjustable ±10%.
Regulation — Line: < 0.1%. Load: < 0.1%.
Combined L/L: < 0.1%.

Ripple: < 0.1% rms
Operating temperature: −20°C to +65°
Package: MIL-T-27 case.

Model Number	E_{out} nom. KV	I_{out} max. mA	Weight Lbs.	Case Style
DRM 105	0.8	18	1½	GA
DRM 115	1	15	1½	GA
DRM 125	1.5	10	1½	GA
DRM 135	2.5	6	1¾	GA
DRM 145	3.5	4	1¾	GA
DRM 155	5	3	1¾	GA
DRM 165	7.5	2	1¾	GA
DRM 175	10	1.5	2	JA
DRM 185	12.5	1.2	2	JA
DRM 195	15	1	2	JA
DRM 205	18	0.8	2	JA
DRM 215	22	0.6	2	JA

MODIFICATIONS AND SPECIALS

Special DRM can be factory adjusted to any output voltage not listed, 200 V to 22 KV. Other specific tions apply. Other input voltages. Very low ripple figures. Wider adjustment range.

Output externally programmable, voltage or resistance. Negative output polarity.

Units can be supplied with reverse input voltage protection or automatic selection of proper inp polarity.

Units can be supplied foamed or epoxy-filled to withstand extreme environmental shock conditio

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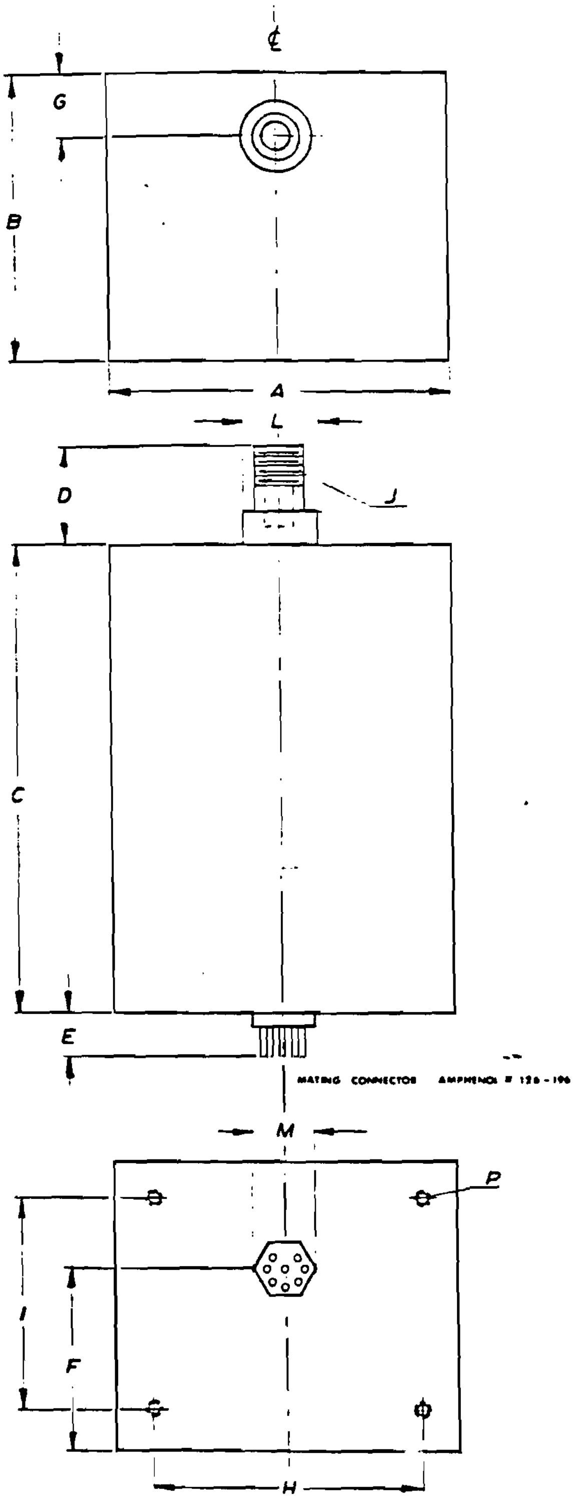


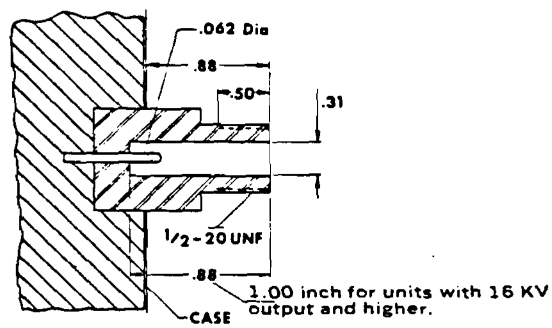
CASE STYLE	GA	JA
A	2.70	3.54
B	2.34	3.04
C	3.77	4.84
D[1]	HV lead	1.00
E	.50	.50
F	1.30	1.88
G	.53	.68
H[2]	2.00	2.75
I[2]	1.75	2.19
J	HV lead	½x20 NC
L	HV lead	.75
M	.63	.63
P	8-32x¼	8-32x¼

Dimensions are in inches.

NOTES

1. This dimension is not fixed when HV lead is used.
2. Mounting holes on center-line.

HV CONNECTOR DETAIL



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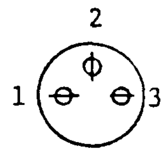
OPERATING INSTRUCTIONS

DRF SERIES



CONNECTIONS:	Pin 1	28 volt return
	Pin 2	+28 volt input
	Pin 3	High Voltage return

Model No.________________ Serial No.___________

1. The High Voltage return is internally tied to the input return, but should be run separately in order not to have short circuit currents on the input line, should they occur. The case is floating and should be connected to the input return. Insulation between case and input can withstand 500 volts, operating.

2. Unit is designed for fixed installation in a system, and therefore has no internal input-reversal protection.

3. Unit can stand overloads and shorts long enough to blow a fast-blow fuse in the input line. Rating of that fuse should be the actual operating current, but no larger than 300 mA.

4. Units are potted and sealed, and are not repairable by user. They can be factory repaired in some cases.

5. Voltage adjustment potentiometer is accessible through small hole at the input end of the unit.

6. Bottom plate of units carry heat-generating components and therefore should be installed on a flat metal surface, using heat-conducting paste, to increase the available heat-sink area.

7. Units contain a switching, DC to DC converter and therefor generate RFI. Input and output contain single, L-sections of RC decoupling, which is adequate for most applications. If RFI is a problem, choke/capacitor filters should be installed at the input and output connections as required.

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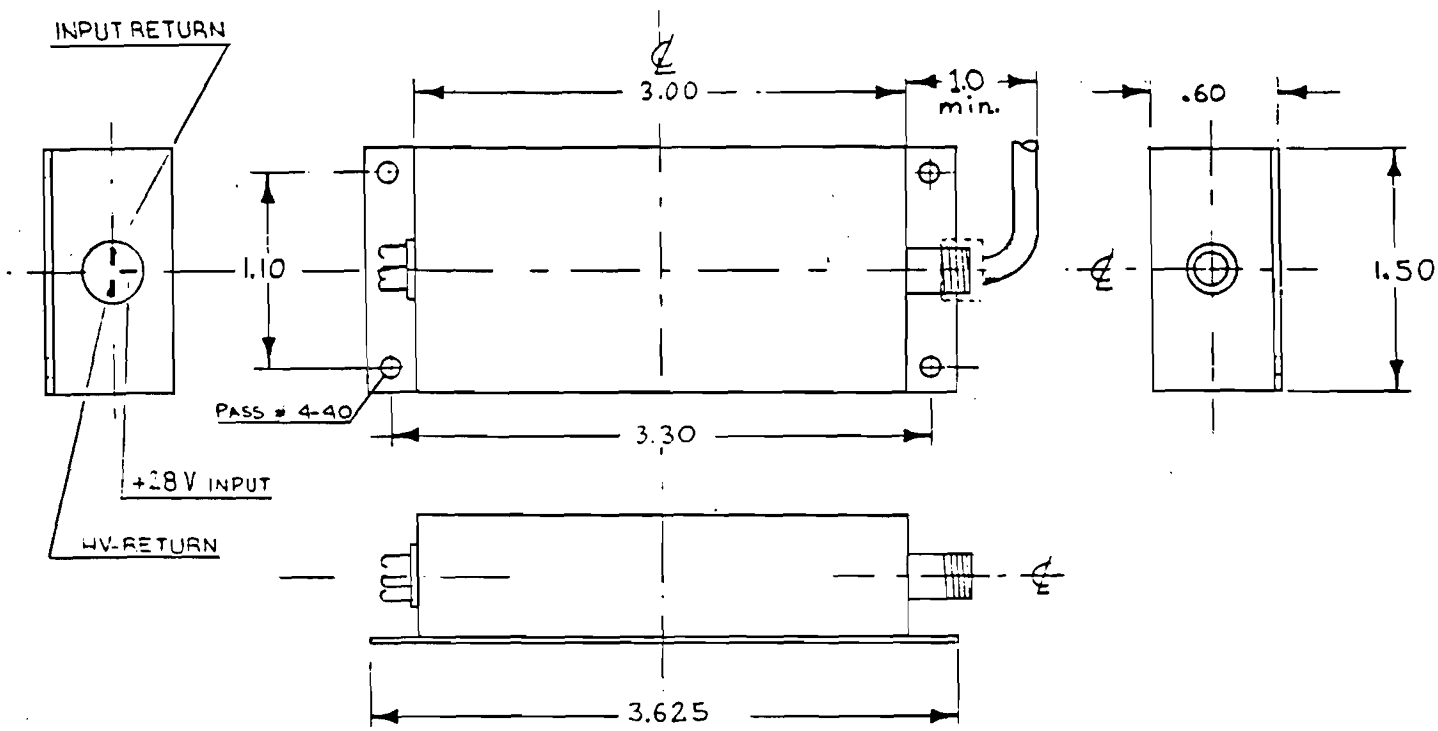


Units with 1 KV or less output use feed-thru terminal instead of HV connector.

HV Connector Part No.:
AMP 830178-1
REYNOLDS 167-9158

REPRESENTED BY:

OPERATING INSTRUCTIONS FOR DRM & DUM SERIES

1. The High Voltage output is on the top of the unit either a wire (high voltage lead) or a connector. The color of the lead has no bearing on the output polarity. The nameplate states the voltage and the polarity.

2. Other connections are on the bottom of the unit:
   - Pin 1 = Program input, 0 to 6.2 volts, the same polarity as the high voltage.
   - Pin 2 = Input return (negative DC).
   - Pin 3 = Positive DC input (+28 VDC)
   - Pin 4 = High voltage return.
   - Pin 5 = Program return.

3. To facilitate initial testing, unit is shipped with the output voltage adjusted to the nameplate voltage under a "no load" condition. Only the DC input (pin 3 & 2) need be connected to the unit for an operational check. Unit is designed for installation into systems and therefore does not contain reverse polarity protection.

4. The remote program capability is activated by connecting a low impedance drive voltage to the program input (pin 1). The program return lead goes to pin 5. Program voltage is approximately 6 volts for the nameplate output voltage, and of the same polarity. Program input impedance is approximately 100 Kohm. A low impedance program voltage automatically overrides the voltage set-in by trimpot RP 1.

5. Input return, high voltage return and program return are common and internally connected together. In the installation, they must be run separately in order to avoid ground loops. (During a high voltage short circuit, large amplitudes are present on the high voltage return and could damage the semiconductors used in the low-voltage section of the unit).

6. The case of the unit should normally be connected to the HV return, but may be floated within 500 volts of the input leads.

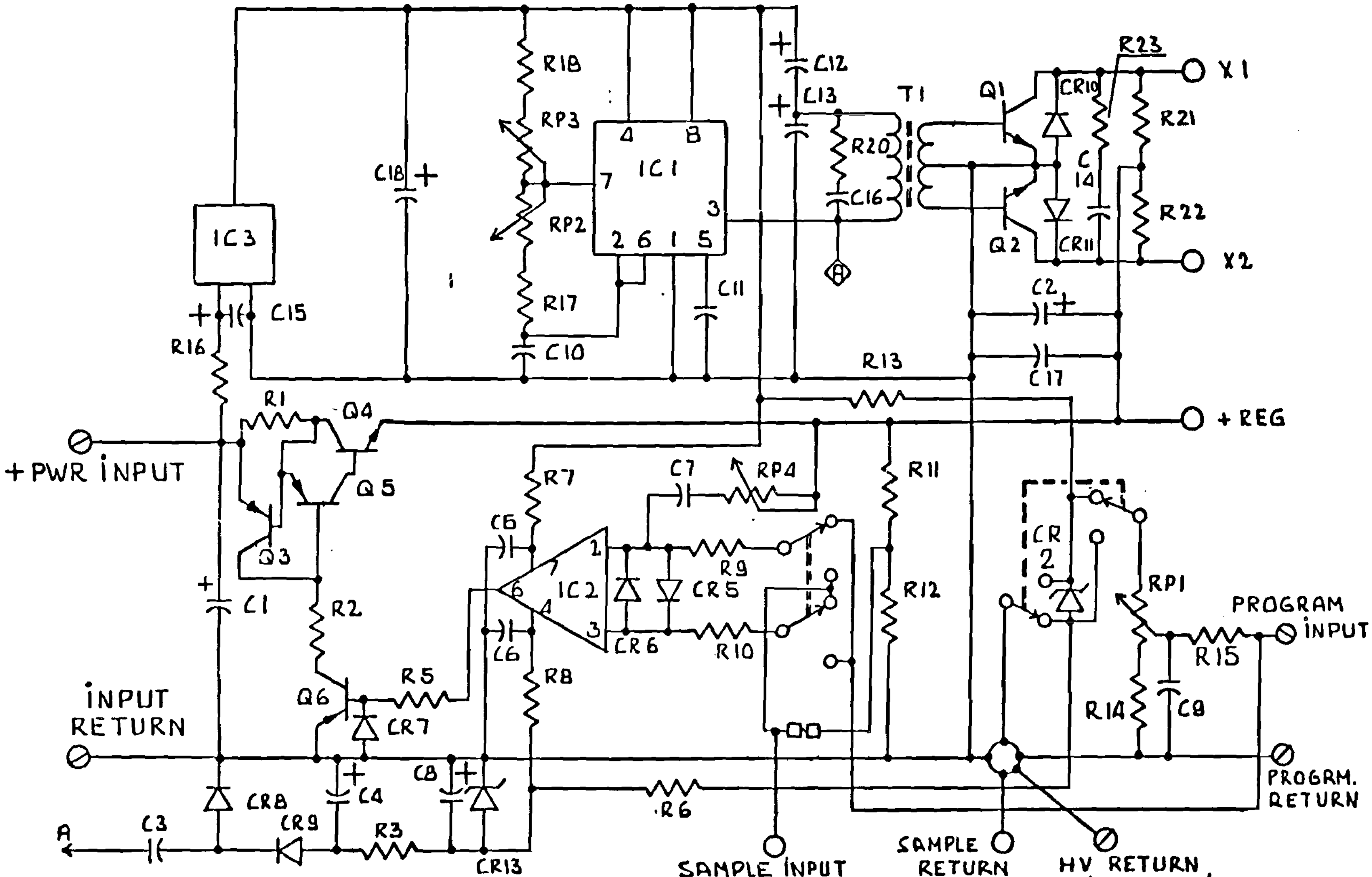
7. The bottom plate of the unit carries heat-generating components and should be installed on a flat metal surface. Heat-conducting paste should be used to insure good heat transfer. Heatsinking must limit the bottom plate temperature to 65°C, even during short circuits, where as much as 50 watts could be dissipated. (Only some units).

8. The 8-32 mounting screws must not penetrate more than one quarter of an inch (1/4") into the bottom plate.

9. The internal current limiting is set by R1. A lower-than-standard value of current limiting can be obtained by increasing R1. (Roughly .47 ohm for 1 Ampere input current). Smaller values of R1 can also be used on the units with -19 option. (This option supplies a 30 watt output on the DRM & DUM series of supplies).

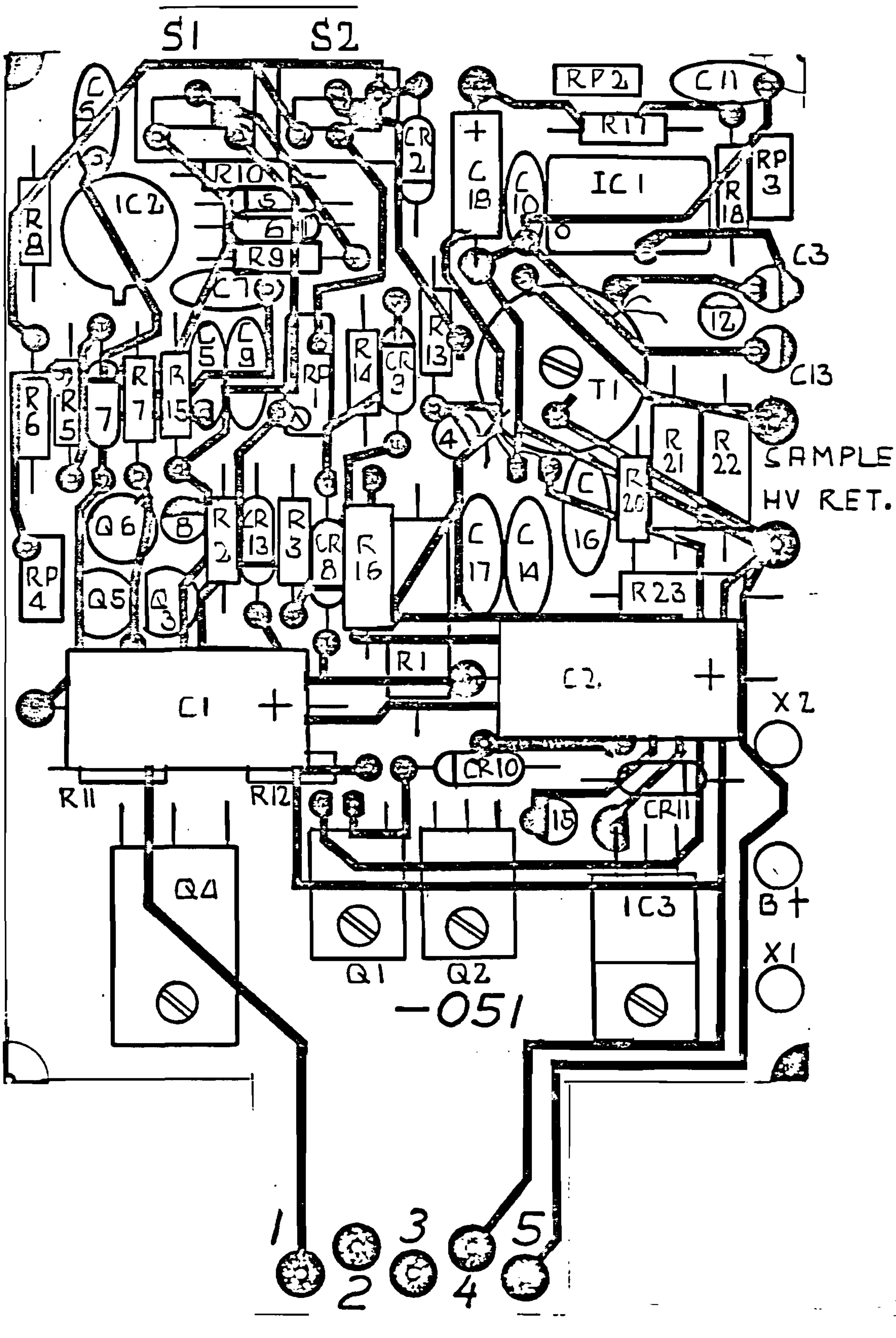
10. Unit should be fused with 1.5 A, slo-blo, except the -19 units, which need a 3 A fuse. The purpose of the fuse is to protect external wiring and <u>other</u> equipment.

11. Unit is shielded and the connections contain some RFI decoupling. If RFI is a problem, choke/capacitor filters should be installed at the input and output connections. The unit's switching frequency is also adjustable with trimpot RP 2. A synch pulse can also be introduced at pin 5 of IC 1, now bypassed, to keep the oscillator locked to an external clock.



S/D DRM/DUM SERIES

JJR 5-10-77


S1
S2
RP2
C11
R17
CR 2
C 18
C 10
IC1
RP 3
R 18
C3
R10
IC2
R8
R9
C7
12
C13
R 13
R 14
CR 9
T1
C 5
C 9
R6
R5
R 7
R 15
RP 1
4
R 21
R 22
SAMPLE
HV RET.
C 16
R 20
Q6
R 2
CR 13
R 3
CR 8
R 16
C 17
C 14
RP 4
Q5
Q 3
R23
R1
C1
C2
X2
R11
R12
CR10
15
CR11
Q4
IC3
B+
X1
Q1
Q2
-051
1
2
3
4
5

PARTSLIST DRM/DUM BOARDS (-050 &-051)

Item	Qty	Description	Part Number	Manufacturer	Ref #
1	2	Cap. Elyt, 100/40		Siemens	C1, 2
2	6	Cap. Tant 1/35	T368 A105M035 AS	Kemet	C3,4,8, C12,13,15
3	7	Cap. Ceram. .01/100		AE	C5,6,7,9 C11,14,17
4	1	Cap. Mica .001/200		CD	C10
5	1	Cap. Ceram. .0022/100		AE	C16
6	1	Cap. Elyt. 22/16		Siemens	C18
7	1	Zener, Ref.	1N825A	Transitron	CR2
8	5	Diode, signal	1N914		CR5,6,7,8,9
9	2	Rectifier	1N4003	Mot	CR10, 11
10	1	Zener, 10V, 400mW	1N5240	Mot	CR13
11	1	Oscillator IC	NE555V	Signetics	IC1
12	1	Op-Amp	741 HC	Fairchild	IC2
13	1	Regulator	78M15UC	Fairchild	IC3
14	2	Transistor, Power	2N5192	Mot	Q1,2
15	2	Transistor, signal	2N4002	Mot	Q3, 5
16	1	Transistor, power	MJE 3055	Mot	Q4
17	1	Transistor, signal	2N2222	Mot	Q6

18	1	Trimpot, 10K	Piher	RP1
19	1	Trimpot, 100K	Piher	RP2
20	1	Trimpot, 2 K	Piher	RP3
21	1	Trimpot, 50K	Piher	RP4
22	1	Resistor, WW .47 ohm, 10% BWH	Ohmite	R1
23	1	Resistor CC, 2.2 K, 1/4 W, 10%	AB	R2
24	2	Resistor CC 22 ohm. 1/4W, 10%	AB	R3,16
25	2	Resistor CC 1 K, 1/4 W, 10%	AB	R5, 20
26	1	Resistor MF, 483 ohm, 1% MK-2		R6
27	2	Resistor, CC, 100 ohm, 1/4W, 10%	AB	R7,8
28	3	Resistor, CC, 10K, 1/4W, 10%	AB	R9,10,17
29	1	Resistor, CC, 18K, 1/4W, 10%	AB	R11
30	1	Resistor, CC, 6.2K, 1/4W, 10%	AB	R12
31	1	Resistor, MF, 1.31 K, 1%, RN55C	Mepco	R13
32	1	Resistor, MF, 13.7K, 1%, RN55C	Mepco	R14
33	1	Resistor, CC, 82K, 1/4W, 10%	AB	R15
34	1	Resistor, CC, 270 ohm, 1/4W, 10%	AB	R18
35	2	Resistor, CC, 1K, 1/2W, 10%	AB	R21,22
36	1	Resistor, CC, 330 ohm, 1/2W, 10% SIT	AB	R23

37	1	Transformer bobbin 120:20:20		AHV	T1
38	2	Core-halves, transformer 1408	UG41408F	Mag Inc	T1
39	2	Switch, DPDT			S1
40	1	Heatsink	4800-000-017	AHV	
41	1	P.C. Board, complt.	-050/051	AHV	
42	1	Insulator, heatsink	-071	AHV	
43	1	Insulating washer, transformer	-072	AHV	
44	2	Insulator, Mica	B08853A001	MOT	
45	2	Insulator, Mica		MOT	
46	2	Insulator, Nylon	B51547F015	MOT	
47	4	Screw, 4-40X5/8 BH			
48	1	Screw, 4-40X1/2 BH			
49	5	Nut, 4-40, sml pattern			
50	1	Washer, flat, #4, sml pattern			
51	1	Washer, flat, #4, regular			
52	2	Washer, compression, #4	B52200F003	MOT	
53	2	Washer, compression, #6		MOT	

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